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DIVISION SNAP-8

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TECHNICAL MEMORANDUM

AUTHOR(S): R. G. Geimer

TITLE: ANALYSIS OF A SNAP-8 EGS BASED ON UNMODIFIED -1 COMPONENT PERFORMANCE

ABSTRACT

An analysis of a SNAP-8 EGS was performed to determine if a system utilizing unmodified -1 components would be capable of producing 35 kwe net output. Test data was used as the basis for components performance where available; notable exceptions are the tube-in-tube boiler and the space radiator. System conditions were determined for operation at the upper and lower temperature limit of the reactor outlet temperature.

Results of the analysis show that the system can produce 35 kwe output without exceeding the -1 component limitations.

Additional information includes a system weight tabulation and radiator areas.

Performance curves for all pertinent components and sample system calculations are presented in appendices.

APPROVED:

DEPARTMENT HEAD P. I. Wood

P. I. Wood

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I. INTRODUCTION

An analysis of a SNAP-8 Electrical Generating System, based on test performance of unmodified -1 PCS components, was performed to determine (a) that a net electrical output of 35 kw can be obtained; (b) what are the system flow rates, pressure and temperature values required to obtain 35 kwe output; and (c) that component limitations are not exceeded.

Estimates of overall system weight and projected areas of the HRL and L/C radiators were also made as additional useful information for this study.

II. SUMMARY OF RESULTS

The results of the analysis show that 35 kwe net output can be obtained from a system comprised of unmodified -1 PCS components when combined with current reactor and representative space radiator design data. The 35 kw electrical output can be obtained at conditions resulting from operation at the limits of the reactor outlet temperature without violating any of the component or system limitations. The system pressures, temperatures and flow rates for operation at the upper limit of the reactor outlet temperature are presented in Figure 1. Figure 1 also contains tables which present system heat balance, electrical power balance and general system performance. Similar data for operation at the lower limit of the reactor outlet temperature are presented in Figure 2.

A heat balance for the lubrication/coolant loop, which is applicable to both the upper and lower temperature limits, is presented in Table I. As indicated in Table I, the lubrication/coolant space radiator must reject 22.2 kw of heat.

A weight summary is presented in Table II, showing a total system weight of 9963 lb. The weights listed are based on the following:

a. The most recently published weight data for the nuclear system.

b. Measured weights of unmodified -1 PCS components to the extent that they are available. For the boiler, design calculations of the tube-in-tube boiler were used. For certain other components, which have not yet been fabricated, such as expansion reservoirs, weight estimates were obtained from documented design data.

c. Previously completed analytical studies of HRL and L/C radiator assemblies, including estimates for shrouding and insulation. Such studies were made for cylindrical configurations radiating from the outer surface only. The HRL radiator was based on a heat rejection of 425 kw. The L/C radiator was corrected for an increase in heat rejection of from 20.1 to 22.2 kw.

The projected areas of the HRL and L/C radiators are presented in Table III. The HRL radiator area of 1100 ft^2 and the L/C radiator area of 411 ft^2 are based on cylindrical shaped radiators designed to reject heat from the outer surface only.

III. CONCLUSIONS

1. The results of the performance show that 35 kwe net output can be produced by a system utilizing unmodified -1 components without exceeding the -1 component limitations.

2. Improvement in the performance of the -1 turbine can be expected as a result of two factors:

a. Design changes, which are being incorporated in all future -1 turbine assemblies, are expected to result in an improvement in turbine efficiency of approximately two percentage points at all reasonable values of liquid carryover. The design modifications include a reduction in leakage flow across the thrust balance seal, a reduction in leakage across the first and second stage nozzle vanes, and a reduction in leakage across the inter-stage diaphragm labyrinth seals.

b. Calculations for the analysis were based on the first stage nozzle operating choked. Subsequent re-evaluation of RPL-2 test data indicated choking occurred in a later stage. A corresponding vapor flow rate adjustment indicates an increase in turbine efficiency of approximately two percentage points. The combined effect of the above factors indicates a turbine efficiency of 59% with 2% liquid carryover from the boiler as compared to 55.5% used in the analysis. This change in efficiency will yield an additional 4 kwe output if system flow rates are unchanged; if the system were rebalanced to maintain 35 kwe output, a significant reduction in system flow rates and reactor power would result.

3. The weight data given in Table II are based largely on existing developmental components for which no weight reduction program has been undertaken. A weight and performance improvement study, now being conducted, will provide the best evaluation of the SNAP-8 EGS flight weight. A significant improvement potential is expected.

IV. GENERAL ASSUMPTIONS

The analysis of the system using -1 components was based on several ground rules and general assumptions which are briefly listed below.

A. Component performance to be based on data of units tested to date.

B. Tube-in-tube boiler to be used with performance based on design data.

C. Liquid carryover from the boiler of 2% of the mercury flow rate under all operating conditions.

D. The only system perturbation to be considered was the affect of NaK temperature variations resulting from operation of the reactor temperature deadband control.

E. Operation in an earth orbit with a cylindrical radiator exposed to maximum solar and earth heat fluxes. (Sun operation)

V. COMPONENT AND SYSTEM PERFORMANCE DATA AND RELATIONSHIPS

A. BOILER

The tube-in-tube boiler considered for use in the system consists of seven tubes, each 30 ft in overall length with a 5 ft plug section.

The boiler performance is based primarily on information contained in TM: 4803:65-2-223, "SNAP-8 Tube-in-Tube Boiler Design Analysis", dated February 1965. The overall pressure drop, on the mercury side, was obtained from the following equation:

$$\Delta P_{B_{tot}} = \left(\frac{W_{HG_{tot}}}{11500}\right)^2 \left[27.3 + 0.7 \Delta T_{PP}\right] \qquad \text{(PSI)}$$

This equation is based on data presented in the referenced TM. The equation for the pressure drop in the liquid, or preheat, section of the boiler was based on data obtained after the issuance of the referenced TM and is as follows:

$$\Delta P_{B_L} = 17\left(\frac{W_{HG_{tot}}}{11500}\right)^2 \qquad \text{(PSI)}$$

Additional boiler performance values were obtained by assuming a constant terminal temperature difference of 30°F between NaK entering the boiler and mercury leaving the boiler. A minimum pinch-point temperature difference of 30°F was assumed as a limiting condition.

The boiler was assumed to operate with 2% liquid carryover for all conditions under consideration. Only the vapor portion of the total mercury flow rate was considered in determining the heat requirements for boiling and superheat regions. A graph of boiler performance, presented in Appendix A, page A-1, was prepared from which primary loop NaK flow requirements can be determined for various mercury flow rates and pinch-point temperature differences at the NaK inlet temperatures of 1330°F and 1280°F.

The equation for pressure drop on the NaK side of the boiler was calculated to be $\Delta P_{B_N} = 1.5\left(\frac{W_N}{48100}\right)^2$ (PSI)

B. BOILER TO TURBINE VAPOR LINE

The pressure drop relationship in the vapor line between the boiler outlet and the turbine inlet was based on calculated values for losses in the line and the filter at the turbine. These values were generally confirmed by test results in RPL-2 and PCS-1. A pressure drop of approximately 6 psi was obtained for the line loss at a flow rate of 11750 lb/hr. A pressure drop of from 3 to 5 psi was obtained for the turbine inlet filter. Therefore, the following relationship was used for line and filter pressure drop:

$$\Delta P_{B-T} = 10\left(\frac{W_{HG_{tot}}}{11750}\right)^2 \qquad \text{(PSI)}$$

A constant temperature drop of 10°F was assumed between the boiler outlet and turbine inlet for all operating conditions.

C. TURBINE ASSEMBLY

Performance of the unmodified -1 turbine assembly was based on tests conducted in RPL-2. The results of these tests indicated that a substantial amount of liquid carryover from the boiler existed. The method for determining the amount of carryover is discussed in memorandum 4933-65-141, "Liquid Mercury Carryover", dated 19 August 1965. This memorandum is reproduced in Appendix A, pages A-2 and A-3. The results of this data analysis were used to determine the turbine efficiency when operating on dry vapor and the effects of varying amounts of liquid carryover on turbine efficiency. A plot showing the effects of liquid carryover on turbine efficiency was prepared on 17 August 1965 for the type of turbine tested in RPL-2. This plot, presented in Appendix A, page A-4, indicates a turbine efficiency of 57% when operating on dry vapor and an efficiency of 55.5% when operating on vapor with 2% liquid carryover.

The constant (K) in the turbine nozzle equation, $W_{HG_V} = K\,P/\sqrt{T}$, was determined to be 1950 for the turbine tested in RPL-2. The next turbine assemblies will have a 5% area increase for all turbine nozzle stages; therefore, K = 2050 was used in the system analysis.

The turbine nozzle constant, K = 2050, is based on the area of the first stage nozzle. Using this nozzle constant throughout the system analysis assumes that the first stage nozzle controls flow through the turbine. Although the results of RPL-2 tests indicate that the first stage nozzle does not operate choked, the use of the first stage nozzle constant will give acceptable results over a limited flow rate range.

Bearing and slinger losses associated with the turbine assembly have been determined from TAA tests to be 1.66 kw.

Losses in the space seals associated with the turbine-alternator assembly have been determined to be 1.56 kw.

D. CONDENSER

The performance of the -1 condenser has been determined to a limited extent by testing to date but has not been shown conclusively. Therefore, performance was estimated on the basis that the condenser operating point would be in the region of high heat transfer effectiveness for both condensing and subcooling. The condenser terminal temperature differences can then be taken as follows:

$$T_{HG_{IN}} - T_{NaK_{OUT}} = 10^{o}F \quad \text{and}$$

$$T_{HG_{OUT}} - T_{NaK_{IN}} = 2^{o}F$$

A condenser pressure drop of 1 psi may also be expected under the conditions of high heat flux. Both the terminal temperature differences and the pressure drop can be assumed to be constant over the range of conditions under investigation.

A constant pressure drop of 0.5 psi, between the turbine exhaust and the condenser inlet was assumed for the operating conditions investigated.

E. ALTERNATOR ASSEMBLY

Performance of the alternator assembly was determined by component tests conducted on the prototype alternator. The results of these tests are shown on curve number 4832-65-00011, "Alternator Performance", dated 2-24-65 which is reproduced in Appendix A, page A-5.

The bearing and slinger losses associated with the alternator assembly have been determined to be 2.5 kw as a result of component tests.

Additional mechanical and electrical losses were determined to be 7.0 kw with an alternator load of 54.5 kw and a power factor of 0.625. The 7.0 kw value includes 1.0 kw for alternator field power.

An allowable alternator output of approximately 87.5 kva is presently estimated to be a conservative limit for extended operation. Previous information indicated that 92 kva may be a permissible value but the tests, from which this data was obtained, were of short duration (30 minutes or less) and may not be valid for long term operation.

F. ELECTRICAL CONTROLS POWER REQUIREMENTS

Power requirements for the speed control components have been determined to be approximately 800 to 900 watts from the results of tests on -X hardware. A value of 1 kw was used in the system analysis.

The minimum parasitic load power required for speed control was determined to be approximately 3 kw from the results of tests conducted with -X hardware. It is expected that design refinements can reduce this value to 1.0 or 1.5 kw. A value of 1.5 kw was used in the system analysis.

The results of tests conducted in RPL-2 indicated that electrical output variations of approximately 3 kw can be expected from system pressure fluctuations at the turbine inlet. Therefore, an additional 3.0 kw was allowed for power stability considerations.

The total electrical controls power requirements (PLR + SC) was, therefore, assumed to be 5.5 kw with a power factor of 0.35 for all operating conditions.

Heat losses in the transformer-reactor reactor assembly are presently estimated to be not greater than 1.0 kw.

G. HRL-RADIATOR PERFORMANCE

Radiator performance was based on the last SNAP-8 radiator design for the reference system. A cylindrical radiator was designed for operation in a 500 nmi earth orbit at the following conditions:

Heat rejection rate	425 kw
Rated flow	39300 lb/hr

Inlet temperature	665°F
Emissivity	0.90
Absorptivity	0.40

The radiator consisted of 130 tubes which would have equal heat rejection and equal NaK flow rate. Therefore, the performance curves can be used to approximate typical radiators with different heat rejection capabilities by varying the number of tubes. Radiator performance over a wide range of operating conditions was shown on a graph entitled, "SNAP-8 Earth Radiator Performance", dated 8-13-64 which is presented in Appendix A, page A-6. Only operation in the sun was considered for the analysis of the -1 component system.

H. PERFORMANCE OF SYSTEM PMA'S

1. Primary NaK-PMA

Performance of the NaK-PMA operating in the primary loop was based on data obtained during tests in LNL-3 and corrected for operation at the expected fluid temperature in the primary loop. The resultant PMA performance is shown in curve number 4932-65-00042, dated 8-3-65 (see Appendix A, page A-7).

The values of head and capacity obtained from the pump performance curve were converted to pressure rise and flow rate values by using the following equations:

$$\Delta P = .3175 \Delta H \quad \text{(PSI)}$$

$$W_N = 367Q \quad \text{(lb/hr)}$$

The motor power factor was obtained from curve number 4832-64-00179, dated 18 February 1965 which is based on in-air tests of the motor. This curve is presented in Appendix A, page A-8.

2. <u>HRL-PMA</u>

Performance of the NaK-PMA operating in the heat rejection loop was based on data obtained during tests in LNL-3 and corrected for operation at the expected fluid temperature in the loop. The resultant PMA performance is shown in curve number 4932-65-00035A, dated 7 August 1965 (see Appendix A, page A-9).

The values of head and capacity obtained from the pump performance curve were converted to pressure use and flow rate values by using the following equations:

$$\Delta P = .3525 \Delta H \quad \text{(PSI)}$$

$$W_{HRL} = 407Q \quad \text{(lb/hr)}$$

The motor power factor for the HRL-PMA was also obtained from curve number 4832-64-00179.

3. <u>Mercury-PMA</u>

Performance of the MPMA was based on component tests of mercury PMA, S/N A1 as shown on curve number 4832-65-00007, dated 6 April 1965 (see Appendix A, page A-10).

The values of head and capacity obtained from the pump performance curve were converted to pressure rise and flow rate values by using the following equations:

$$\Delta P = 5.61 \Delta H \quad \text{(PSI)}$$

$$W_{HG_{tot}} = 6480Q \quad \text{(lb/hr)}$$

The power factor for the motor was obtained from curve number 4832-64-00180, dated 18 February 1965 (see Appendix A, page A-11).

4. <u>L/C-PMA</u>

Performance of the L/C-PMA was based on data obtained from component tests of four units. The resultant ~~average~~ PMA performance is shown in curve number 4932-65-00038, dated 18 July 1965 which is reproduced in Appendix A, page A-12.

The motor power factor was obtained from curve number 4832-65-00006, dated 18 February 1965 (see Appendix A, page A-13).

I. SYSTEM LOOP DATA

1. <u>Primary Loop</u>

The pressure drops in the primary loop may be defined as those existing in the reactor, the boiler and in the loop piping. The following relationships were used to insure that pump capability would not be exceeded for any required flow rate:

$$\Delta P_{R_X \text{ INTERFACE}} = 4.3\left(\frac{W_N}{41300}\right)^2$$ (PSI) - based on data used for Ref. Sys. 'E', Dwg No. 090122

$$\Delta P_{\text{PIPING}} = 9.6\left(\frac{W_N}{41300}\right)^2$$ (PSI) - based on data used for Ref. Sys. 'E'

$$\Delta P_{\text{BOILER}} = 1.5\left(\frac{W_N}{48100}\right)^2$$ (PSI) - based on data presented in TM:4803:65-2-223

The limiting flow rate for the primary loop was determined to be 51500 lb/hr by finding the intersection of the pump performance curve and the system pressure drop curve. A plot showing this intersection point is presented in Appendix A, page A-14.

Absolute pressure levels in the primary loop are determined by the following limitations: (a) pressure in the reactor must not exceed 50 psia or be less than 35 psia when the NaK temperature is 1300°F or above, (b) PN-PMA inlet pressure should not be less than the pump net positive suction pressure of 16.5 psia. A margin of 3 psia above the minimum value for the reactor was used in defining the loop pressure level. This value, however, is subject to some variation which may depend on the operating characteristics of a flight expansion reservoir.

2. <u>Heat Rejection Loop</u>

The pressure drops in the heat rejection loop may be defined as those existing in the condenser, the radiator and the loop piping. The following relationships were used to determine the pump requirements:

$$\Delta P_{COND} = 4.0 \left(\frac{W_{HRL}}{39500} \right)^2$$

(PSI) - based on estimated pressure drop for modified -1 condenser

$$\Delta P_{RAD} \equiv 18.8 \left(\frac{W_{HRL}}{39300} \times \frac{130}{n} \right)^2$$

(PSI) - based on 425 kw ref. sys. radiator, where n = no. of radiator tubes

$$\Delta P_{PIPING} = 7.7 \left(\frac{W_{HRL}}{31800} \right)^2$$

(PSI) - based on data used for Ref. Sys. 'E'

The limiting flow rate for the heat rejection loop was determined to be 46500 lb/hr by finding the intersection of the pump performance curve and the system pressure drop curve. The system pressure drop curve is based on the assumption that radiator pressure drop would remain nearly constant with changes in flow rate. The flow number of radiator tubes would be varied in proportion to the flow rate so that the flow rate and heat rejection per tube would remain constant. A plot showing the intersection of the pump performance curve and the system pressure drop curve is presented in Appendix A, page A-14.

Absolute pressure levels in the heat rejection loop are determined by the minimum HRL-PMA inlet pressure of 13.5 psia. This value is determined from the NPSH requirement indicated on curve 4932-65-00035A, dated 7 August 1965 (see Appendix A, page A-9). A margin of 5 psia above the minimum value was assumed in defining the loop pressure level. This value, however, is subject to some variation which may depend on the operating characteristics of a flight expansion reservoir.

3. Mercury Loop

The line losses between the condenser outlet and pump inlet is less than 0.1 psi and assumed negligible. Elevation heads were not considered in the system analysis.

The pressure drop between the pump outlet and boiler inlet will be determined primarily by an orifice or trim valve. The pressure drop value was determined at the low flow rate value and was then assumed to be proportional to $W_{H_G}{}^2$ for other operating conditions.

4. L/C Loop

Since L/C flow requirements have not been firmly established for all components, a flow rate of approximately 8000 lb/hr was assumed to determine PMA electrical requirements. These requirements were assumed to be constant for all operating conditions considered. The component heat losses which must be dissipated in the L/C loop are summarized in Table I. The resultant heat rejection rate for the L/C radiator is 22.2 kw.

8-27-65

TABLE I

L/C LOOP - HEAT BALANCE

I.	HEAT INPUT		22.2 KW
	TAA Space Seal	1.56	
	TA Bearings & Slingers	1.66	
	TAA Alternator	9.50	
	MPMA Space Seal	1.07	
	MPMA Motor Losses	1.57	
	PN-PMA	2.53	
	HRL-PMA	1.92	
	L/C-PMA	1.43	
	Transformer-Reactor Assembly	1.00	
II.	HEAT REJECTION		
	L/C Radiator		22.2 KW

TABLE II

EGS WEIGHT SUMMARY

Based on the unmodified -1 components. This is not the reference system.

I.	NUCLEAR SYSTEM			2714 lb.
	Reactor		566	
	Shield		1930	
	Miscellaneous		189	
	NaK Inventory		29	
II.	POWER CONVERSION SYSTEM			4183 lb.
	A. Primary NaK Loop		896	
	Pump Motor Assembly	161		
	Parasitic Load Resistor	60		
	Boiler (Tube-in-Tube)	277		
	Startup Heat Exchanger	20		
	Expansion Reservoir	134		
	Piping and Miscellaneous	42		
	NaK Inventory	202		
	B. Mercury Loop		1248	
	Turbine-Alternator Assembly	701		
	Pump Motor Assembly	175		
	Condenser	92		
	Injection System	86		
	Piping and Miscellaneous	59		
	Mercury Inventory	135		
	C. Heat Rejection Loop		290	
	Pump Motor Assembly	162		
	Expansion Reservoir	37		
	Piping and Miscellaneous	24		
	NaK Inventory	56		
	Auxiliary Start Loop	11		

D.	Lube/Cool Loop		179	
	Pump Motor Assembly	26		
	Expansion Reservoir	35		
	Piping and Miscellaneous	38		
	4P3E Inventory	80		
E.	Electrical System		960	
	Start Programmer	15		
	Control Assembly - Low Temperature	107		
	Transformer-Reactor Assembly	307		
	Inverter Assembly	316		
	Battery Assembly	140		
	Harness Assembly	60		
	Miscellaneous	15		
F.	PCS Structure		610	
III.	RADIATOR ASSEMBLY			3066 lb.
A.	HRL Radiator Assembly		2147	
	Radiator	1543		
	Shroud and Insulation	482		
	Piping	32		
	NaK Inventory	90		
B.	L/C Radiator Assembly		919	
	Radiator	630		
	Shroud and Insulation	220		
	Piping	18		
	Inventory	59		
			TOTAL	9963 lb.

NOTE: Weight estimates are based on:

1. Nuclear System: Atomics-International SNAP-8 Progress Report, NAA-SR-11092, dated 15 June 1965.
2. Power Conversion System: Measured weight of unmodified -1 PCS components, where possible. For certain components (e.g., expansion reservoirs), weight estimates were derived from documented design data.
3. Radiator Assembly: Analytical studies on cylindrical radiator configurations. The L/C radiator was corrected for an increase in heat rejection from 20.1 to 22.2 kw.

8-27-65

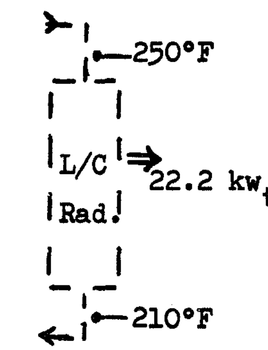
TABLE III

RADIATOR PROJECTED AREA

HRL Radiator	1100 ft^2
L/C Radiator	411
Total	1511 ft^2

SNAP-8 EGS PERFORMANCE
BASED ON UNMODIFIED -1 COMPONENTS

UPPER TEMPERATURE LIMIT FROM REACTOR



PCS POWER BALANCE

HRL Radiator		444.0 kw_t
L/C Radiator		22.2
Line and Component Losses	Pri.	6.0
	Hg.	1.0
Electrical Power to Vehicle		35.5
		508.7

ELECTRICAL POWER BALANCE

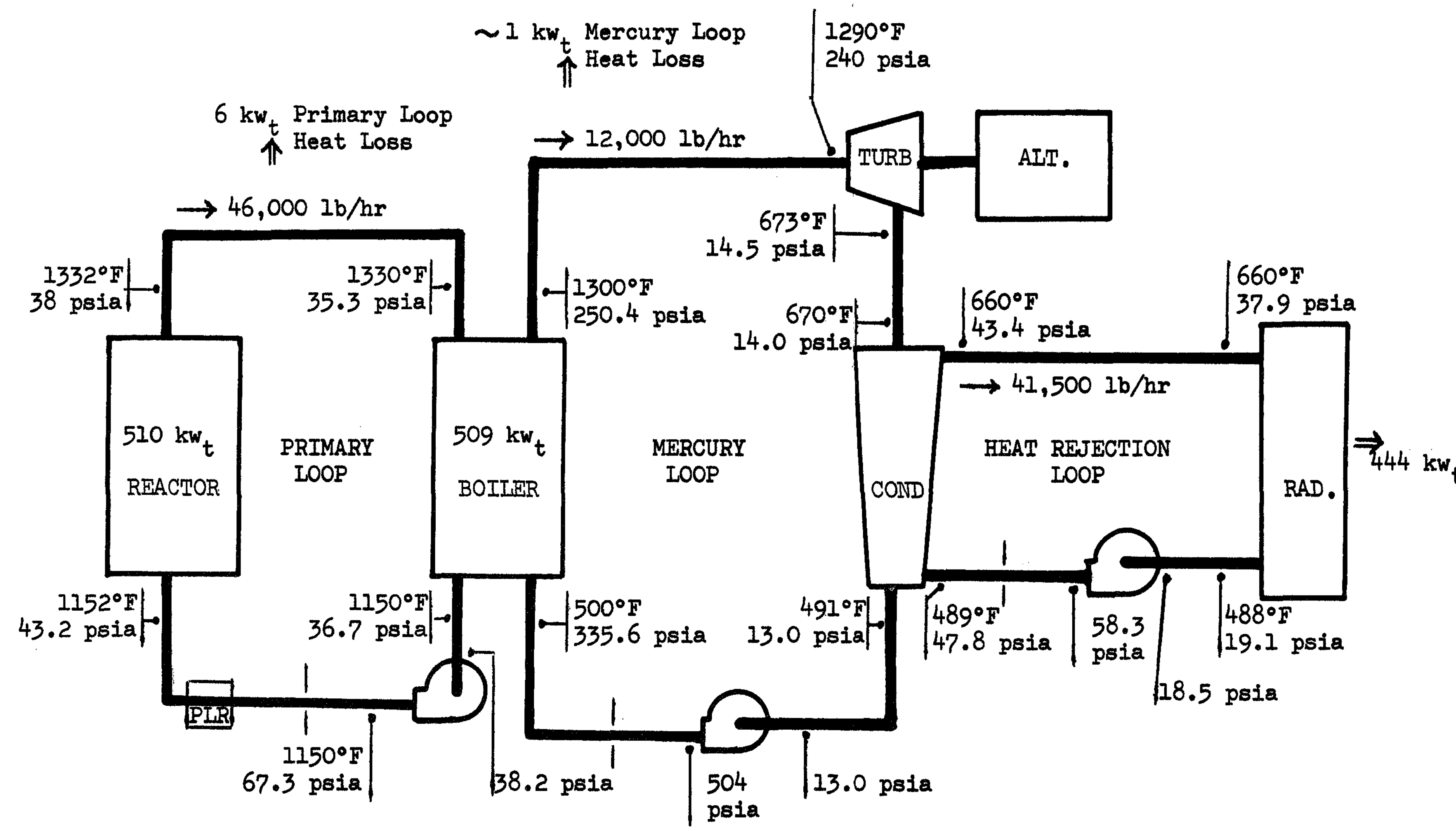
Alternator Output		54.0 kw_e
Loads		
Vehicle Load		35.5
PCS Controls		1.0
Parasitic Load:	Min. Resid.	1.5
	Pwr. Stability	3.0
PN-PMA		4.3
HRL-PMA		4.4
MPMA		2.86
L/C - PMA		1.43
		53.99

TAA PERFORMANCE

Turbine Power	66.0 kw_t
TA Seal and Bearing Loss	3.3 kw
Turbine Efficiency	55.5 %
Alternator Efficiency	86 %

SYSTEM PERFORMANCE

Reactor Power (to PCS)	510 kw_t
System Efficiency	6.9 %



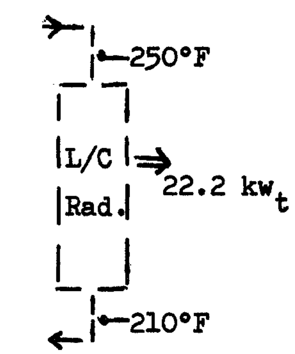
Notes:

1. Performance shown is based on test results of unmodified -1 components obtained prior to July 1965. Turbine design changes now in process are not accounted for. This is not the reference system.
2. Boiler performance based on tube-in-tube design.
3. Boiler liquid carryover of 2% is assumed.
4. Operation in 300 nmi earth orbit with maximum sun and earth heat load is assumed.

Figure 1

SNAP-8 EGS PERFORMANCE BASED ON UNMODIFIED -1 COMPONENTS

LOWER TEMPERATURE LIMIT FROM REACTOR



PCS POWER BALANCE

HRL Radiator		461.0 kw$_t$
L/C Radiator		22.2
Line and Component Loss	Pri.	6.0
	Hg.	1.0
Electrical Power to Vehicle		36.3
		526.5

ELECTRICAL POWER BALANCE

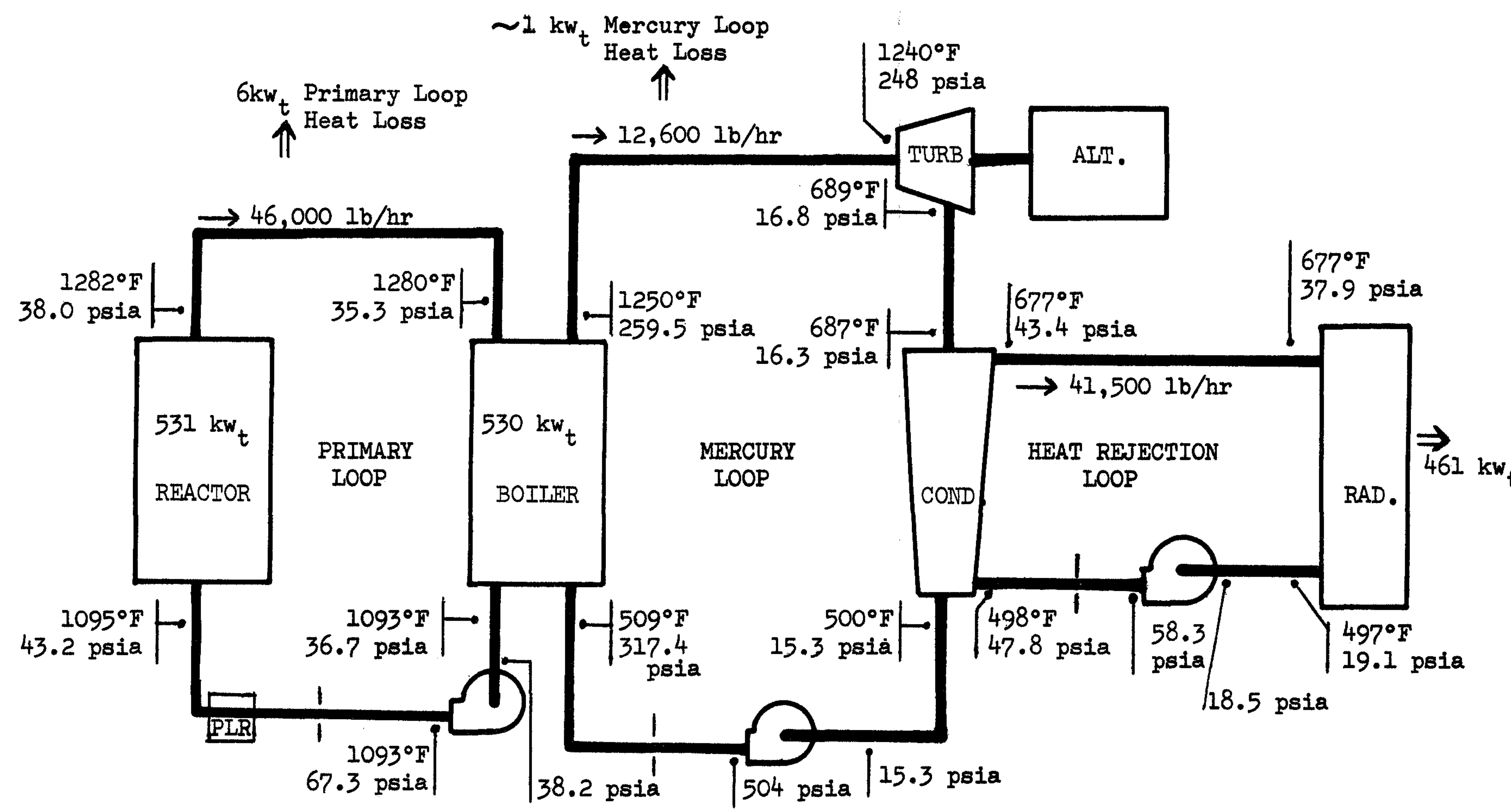
Alternator Output	54.8 kw$_e$
Loads	
Vehicle Load	36.3
PCS Controls	1.0
Parasitic Load Min. Resid.	1.5
Pwr. Stability	3.0
PN-PMA	4.3
HRL-PMA	4.4
MPMA	2.87
L/C - PMA	1.43
	54.80

TAA PERFORMANCE

Turbine Power	67.1 kw$_t$
TA Seal and Bearing Loss	3.3 kw
Turbine Efficiency	55.5 %
Alternator Efficiency	86 %

SYSTEM PERFORMANCE

Reactor Power (to PCS)	531 kw$_t$
System Efficiency	6.8 %



Notes:

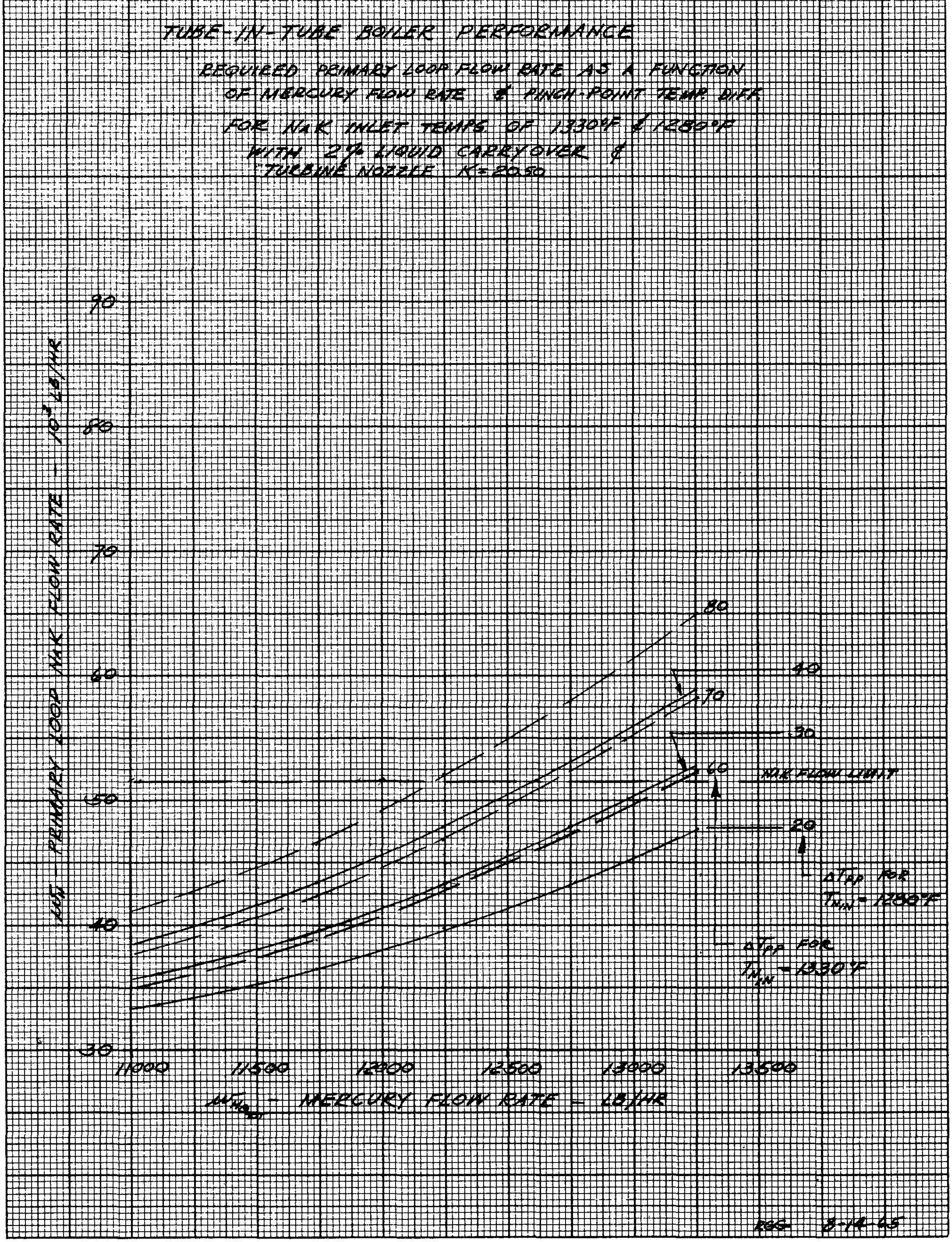
1. Performance shown is based on test results of unmodified -1 components obtained prior to July 1965. Turbine design changes now in process are not accounted for. This is not the reference system.
2. Boiler performance based on tube-in-tube design.
3. Boiler liquid carryover of 2% is assumed.
4. Operation in 300 nmi earth orbit with maximum sun and earth heat load is assumed.

Figure 2

APPENDIX A

REFERENCE MATERIAL

The component performance reference material used as the basis of the system analysis is presented herein, except for technical memorandum. The reference material represents the latest information obtainable from the various design groups and is not necessarily formally released information. Changes in the component performance values may be made when information is formally released.


TUBE-IN-TUBE BOILER PERFORMANCE
REQUIRED PRIMARY LOOP FLOW RATE AS A FUNCTION OF MERCURY FLOW RATE & PINCH-POINT TEMP. DIFF.
FOR NaK INLET TEMPS OF 1330°F & 1280°F
WITH 2% LIQUID CARRYOVER &
TURBINE NOZZLE K=20.50
90
80
70
60
50
40
30
11000
11500
12000
12500
13000
13500
MERCURY FLOW RATE — LB/HR
PRIMARY LOOP NaK FLOW RATE — 10^3 LB/HR
80
70
60
40
30
20
NaK FLOW LIMIT
ΔT_{PP} FOR $T_{N_{IN}}$ = 1280°F
ΔT_{PP} FOR $T_{N_{IN}}$ = 1330°F
RGG 8-14-65

AEROJET-GENERAL CORPORATION

INTER-OFFICE MEMO
10-007-102

TO: Distribution

DATE: 19 August 1965
4933-65-141:JNH:of

FROM: J. N. Hodgson

SUBJECT: Liquid Mercury Carryover

DISTRIBUTION: E. S. Chalpin, M. G. Cherry, E. Eber, L. B. Kelly, A. H. Kreeger, R. G. Geimer, C. S. Mah, P. I. Wood, G. Oiye, C. G. Boone

Enclosure: (1) Liquid Mercury Carryover, RPL-2, -1 Boiler 4933:65-321 curve

The method used for determining the magnitude of liquid mercury carryover is by taking the ratio of the vapor flow rate to the liquid flow rate. The difference from unity of the ratio indicates the liquid carryover. This method works well for measuring the difference in carryover between one flow rate and another. However, for determining absolute magnitudes of carryover, the method is limited in accuracy due to instrumentation limitations.

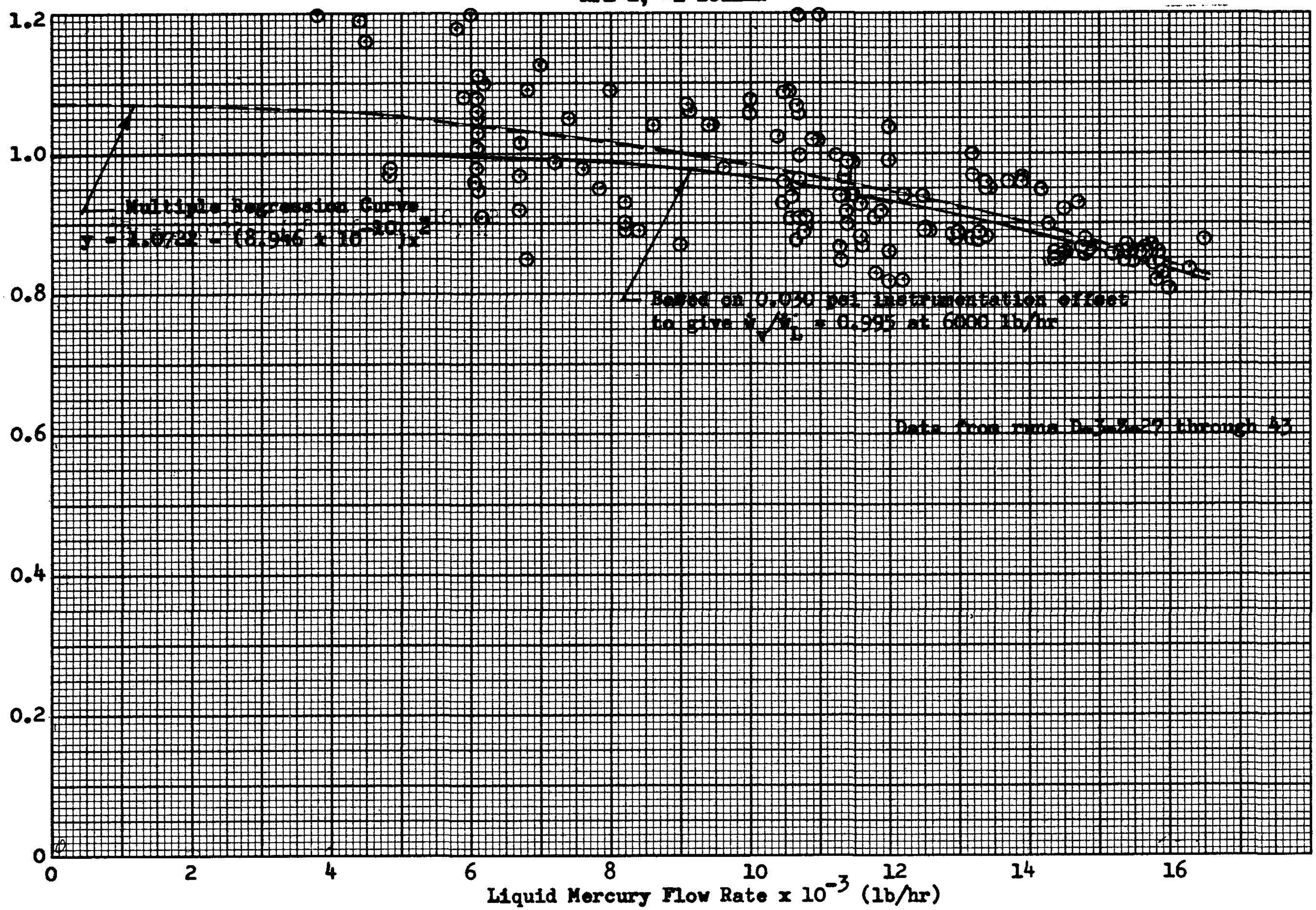
The instrumentation limitation encountered in measuring carryover arises from the fact that only small differences between vapor and liquid flow rate are being measured. Whereas changes in the quantity of carryover can be measured with relative accuracy, absolute values are less accurate due to instrumentation offsets. This is demonstrated by the dotted curve of the enclosure. The dotted curve is a statistically averaged curve through the datum points shown (Reference: Memo 4921-65-0023). The curve is seen to asymptotically approach a flow rate ratio of 1.07 as the flow rate approaches zero. This is physically impossible since the vapor flow rate cannot exceed the liquid flow rate. The shape of the curve is assumed to be correct with the 7% excess flow rate ratio being attributed to an offset in the instrumentation.

A corrective procedure has been applied to the statistically-derived curve to adjust its values so as to make absolute magnitudes of liquid carryover more accurately obtainable. The assumptions have been made that the flow rate ratio is essentially unity at low flow rates ($\leq$6000 lb/hr) and that the upward-shift of the curve is due to an instrumentation offset. The corrective procedure has been to apply an assumed instrumentation offset to the entire length of the statistical curve. The applied offset naturally causes a greater percentage change in the curve at low flow rates than it does at high flow rates. Consequently, another variable is introduced in that a decision must be made with respect to the choice of flow rate at which the assumed offset will just shift the statistical curve to approach unity. Inasmuch as the lowest flow rate at which significant amounts of data are available is 6000 lb/hr, this flow rate was chosen as the point of normalization. The offset was selected so as to give a flow rate ratio of 0.995 at 6000 lb/hr. The same offset was then applied over the length of the curve.

The solid curve of the enclosure shows the resulting modified statistical curve. This curve represents the best carryover data presently available.

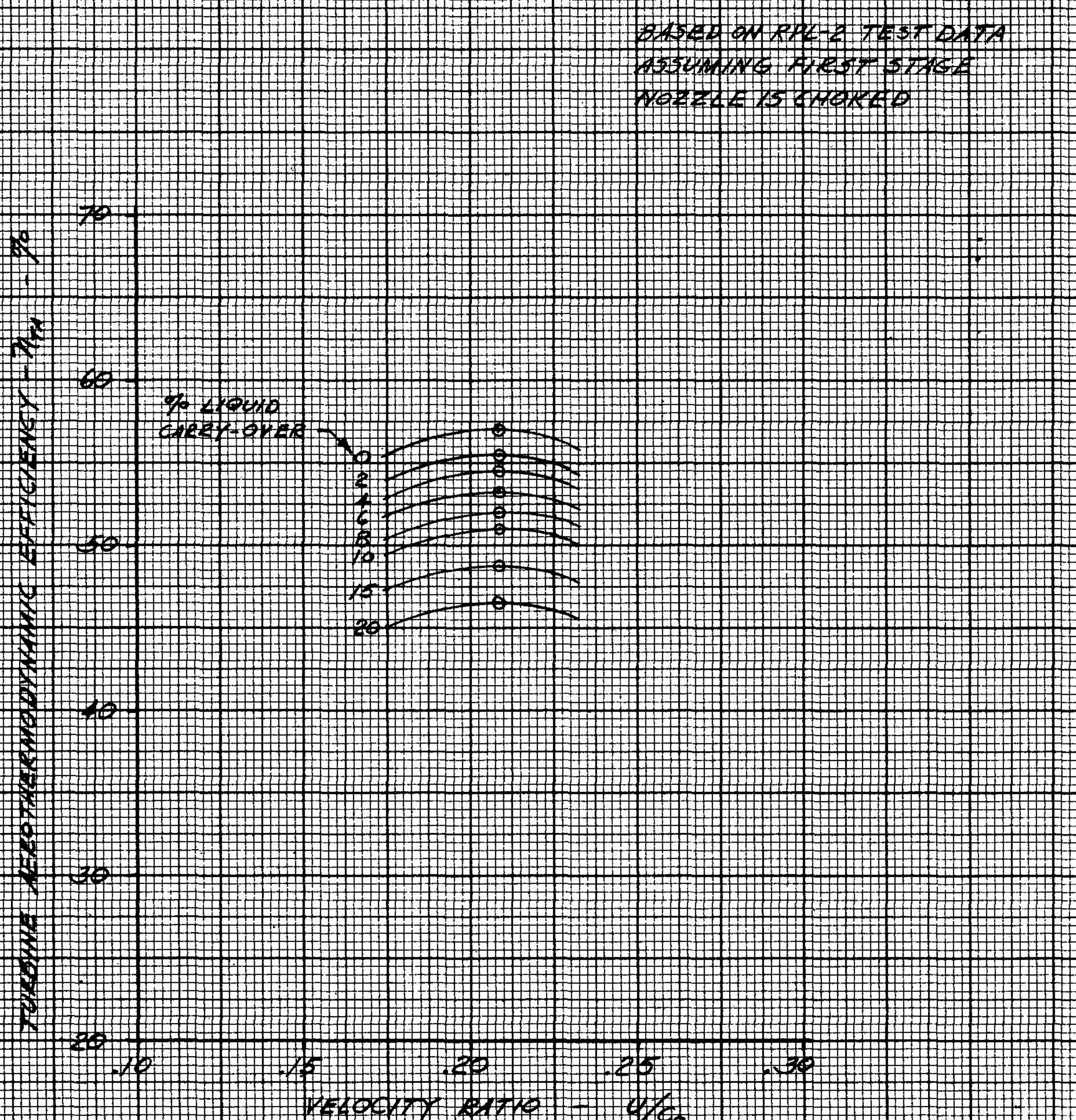
J. N. Hodgson
J. N. Hodgson
Heat Exchanger Section
SNAP-8 Division

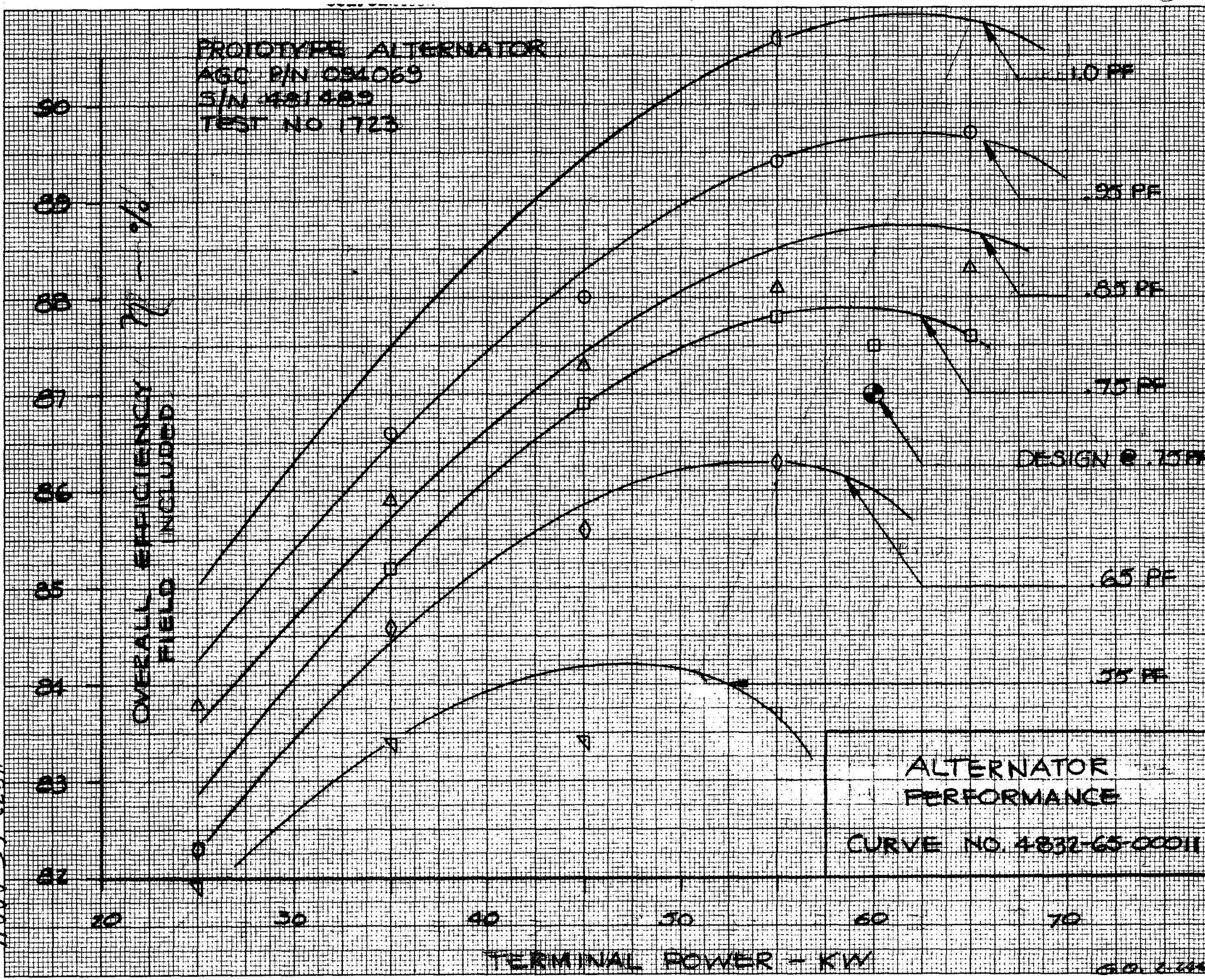
LIQUID MERCURY CARRYOVER
RPL-2, -1 BOILER



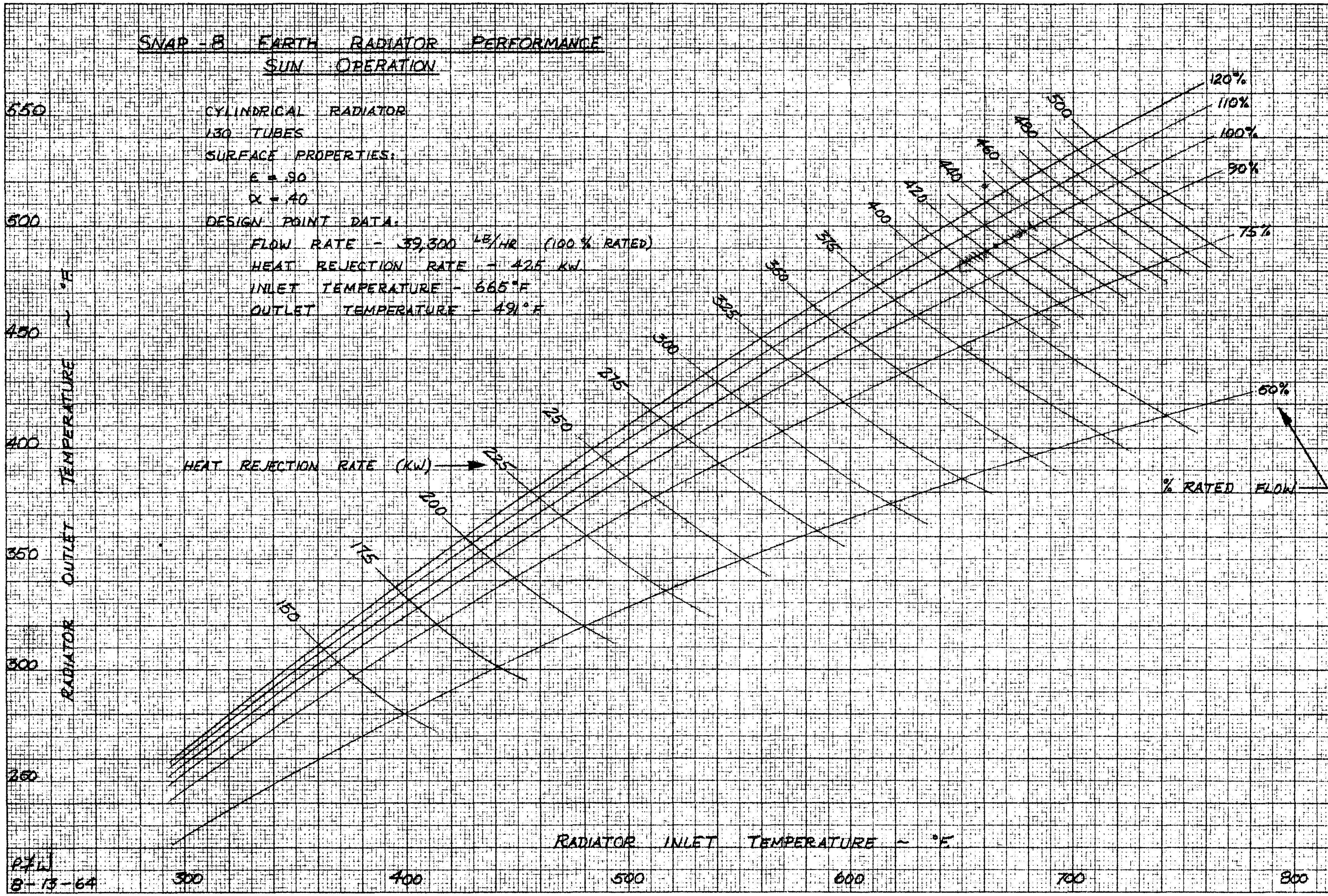
4933:65-321

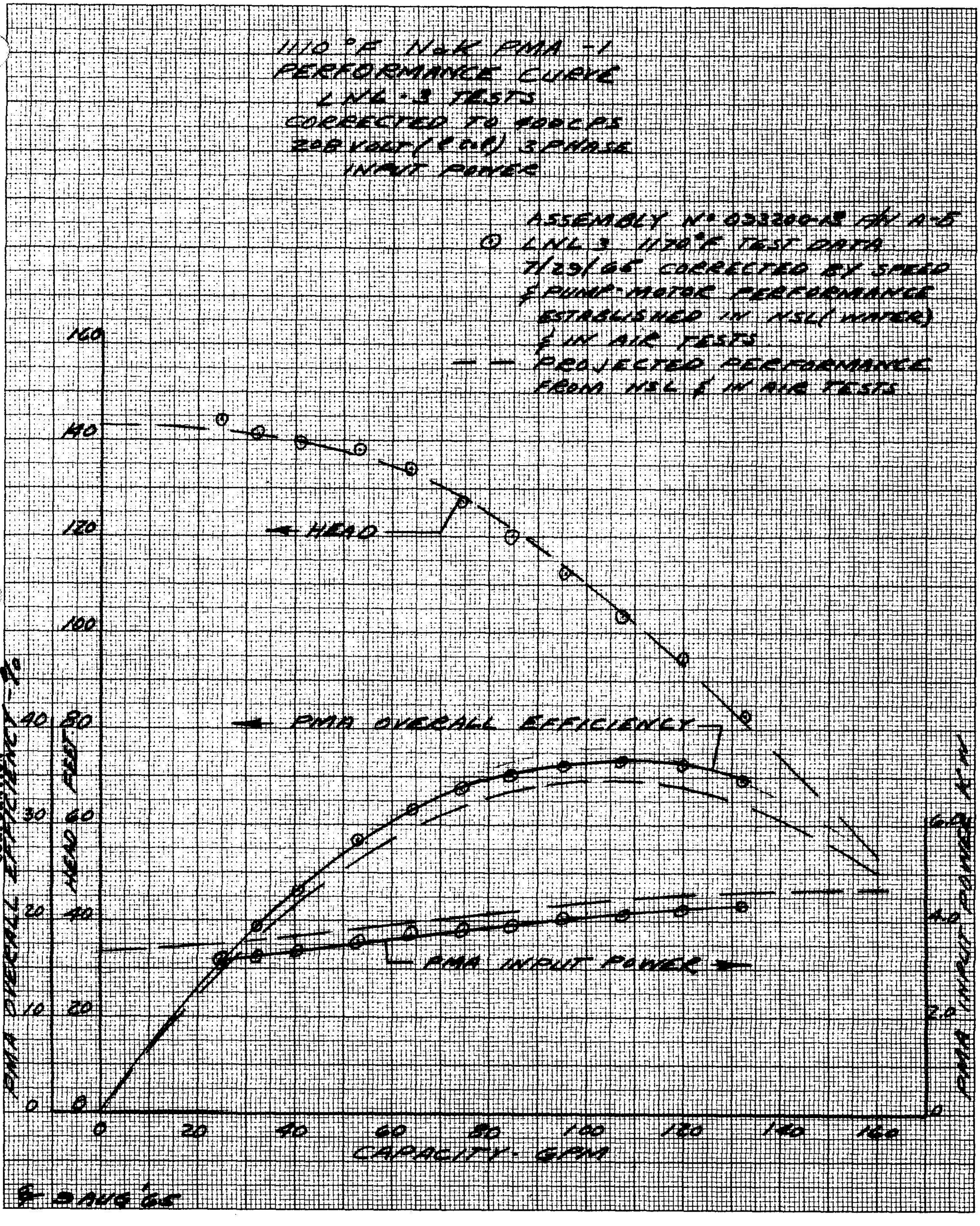
EFFECT OF LIQUID CARRY-OVER ON TURBINE EFFICIENCY



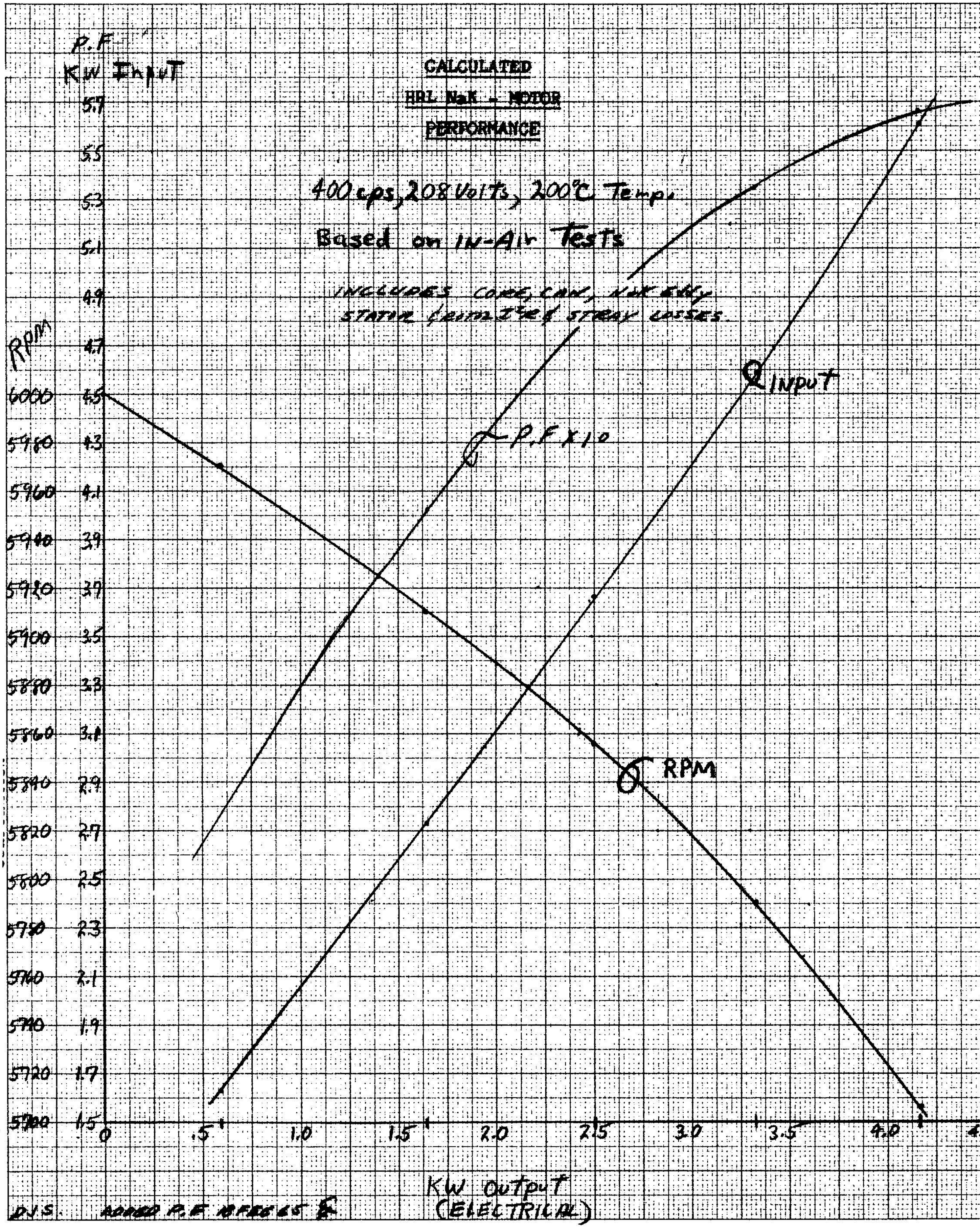


4832-65-00011

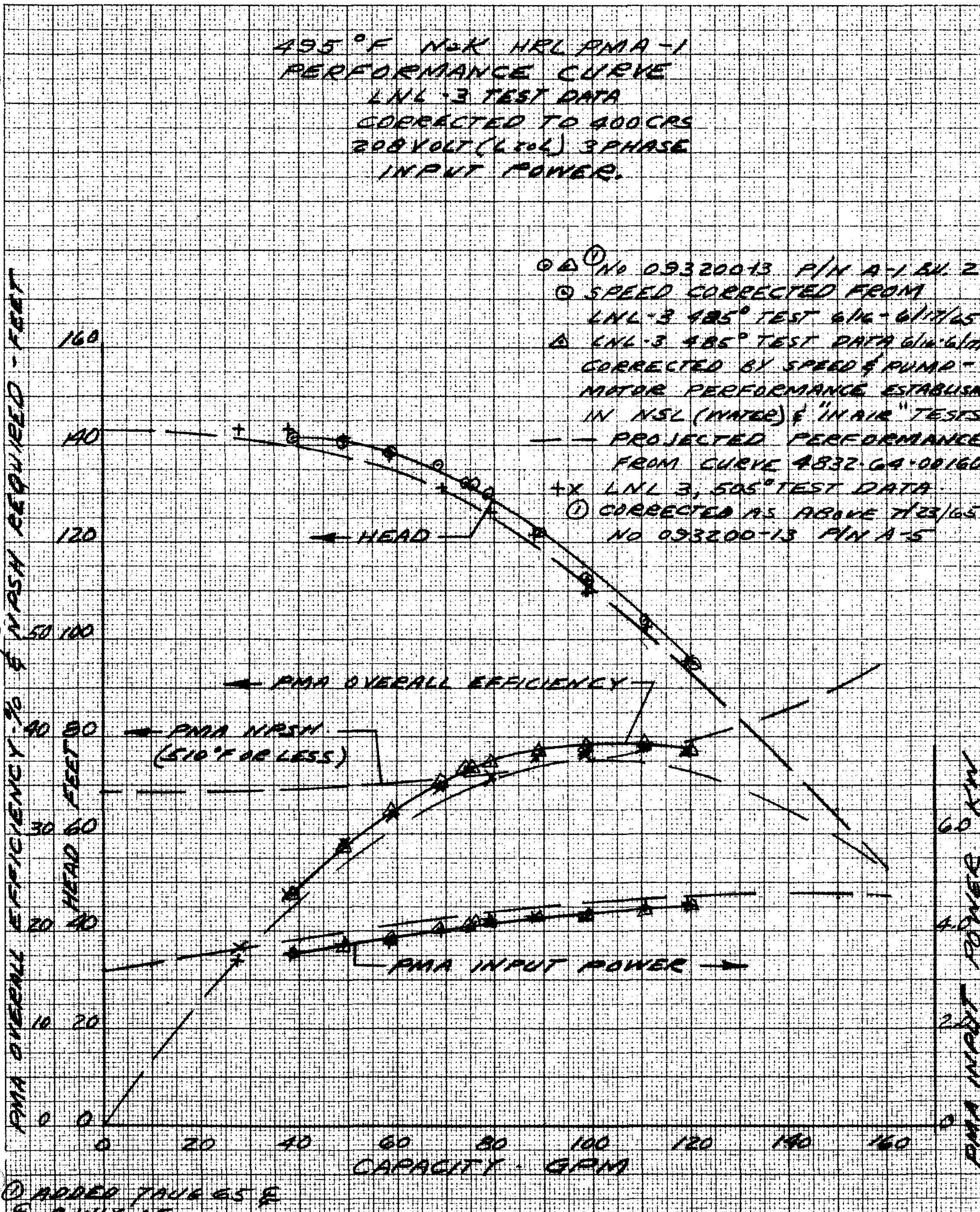

SNAP-8 EARTH RADIATOR PERFORMANCE
SUN OPERATION
CYLINDRICAL RADIATOR
130 TUBES
SURFACE PROPERTIES:
ε = .90
α = .40
DESIGN POINT DATA:
FLOW RATE - 39,300 LB/HR (100% RATED)
HEAT REJECTION RATE - 425 KW
INLET TEMPERATURE - 665°F
OUTLET TEMPERATURE - 491°F
HEAT REJECTION RATE (KW)
% RATED FLOW
120%
110%
100%
90%
75%
60%
150
175
200
225
250
275
300
325
350
375
400
420
440
460
480
500
RADIATOR OUTLET TEMPERATURE ~ °F
550
500
450
400
350
300
250
RADIATOR INLET TEMPERATURE ~ °F
300
400
500
600
700
800
PFW
8-13-64



4932-65-00042



CALCULATED
HRL NaK - MOTOR
PERFORMANCE
400 cps, 208 Volts, 200°C Temp.
Based on IN-Air Tests
INCLUDES CORE, CAN, NaK EDDY
STATOR & ROTOR I²R & STRAY LOSSES
P.F
KW INPUT
RPM
Q INPUT
P.F X 10
σ RPM
KW OUTPUT
(ELECTRICAL)
D.J.S.
ADDED P.F 18 FEB 65



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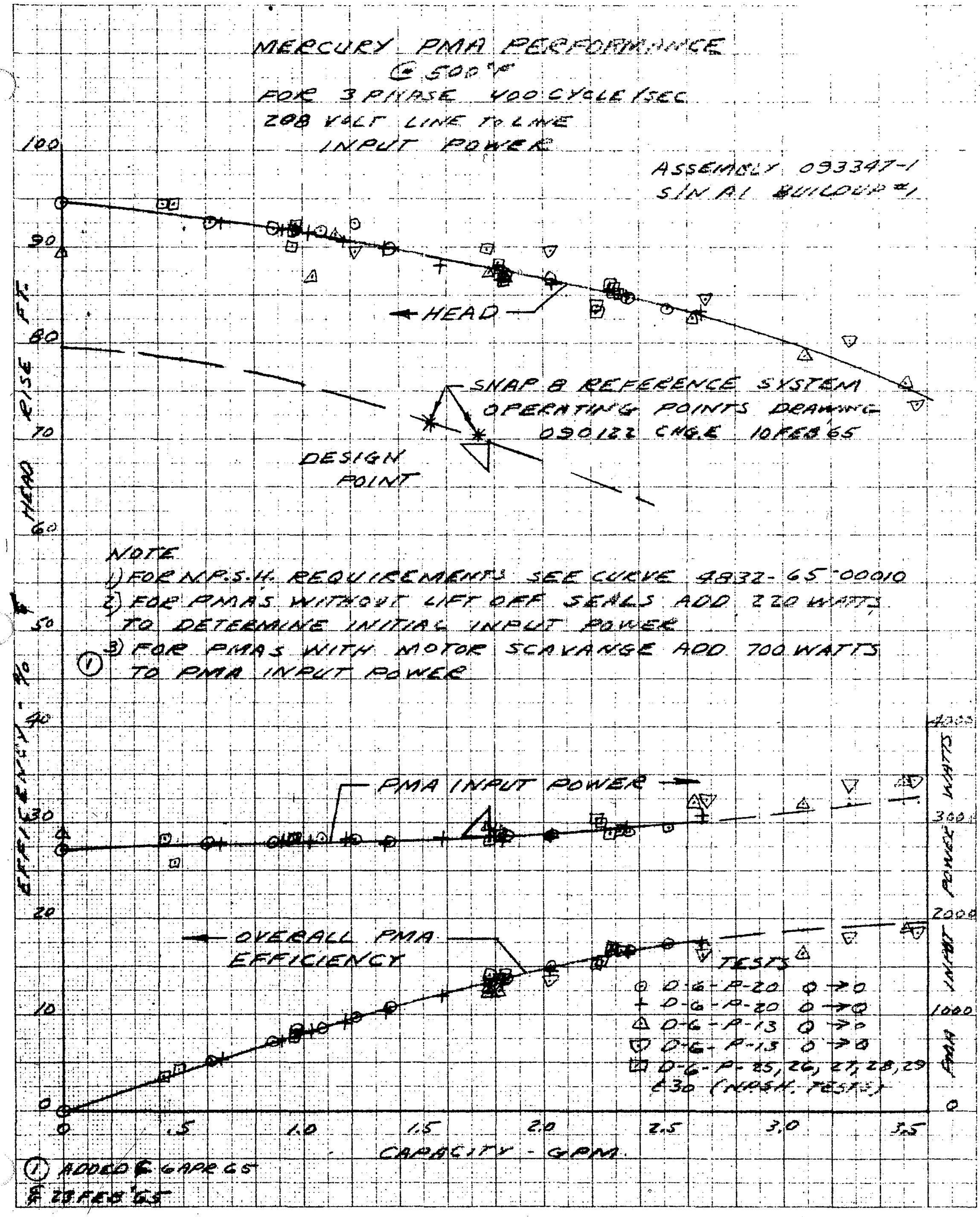
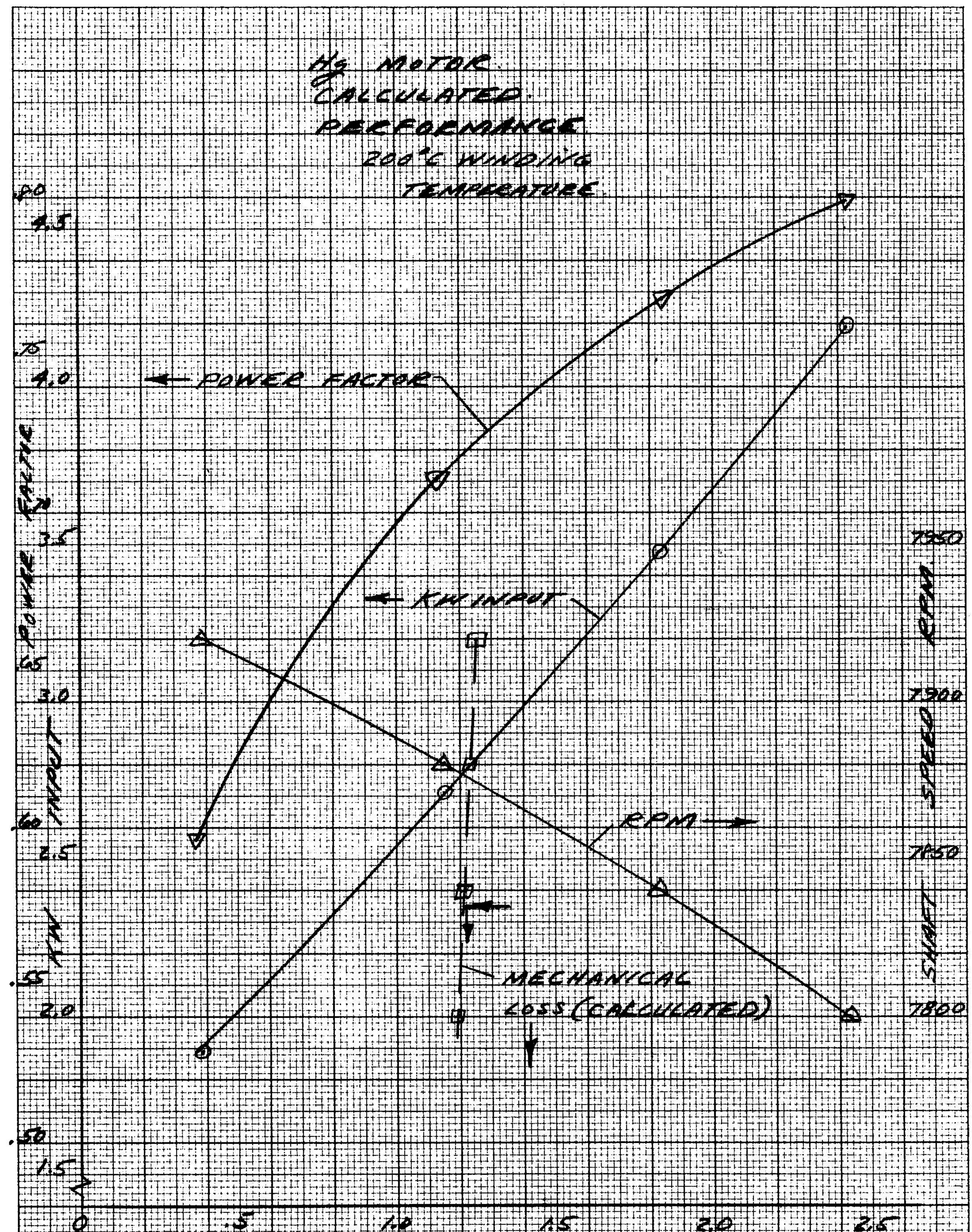
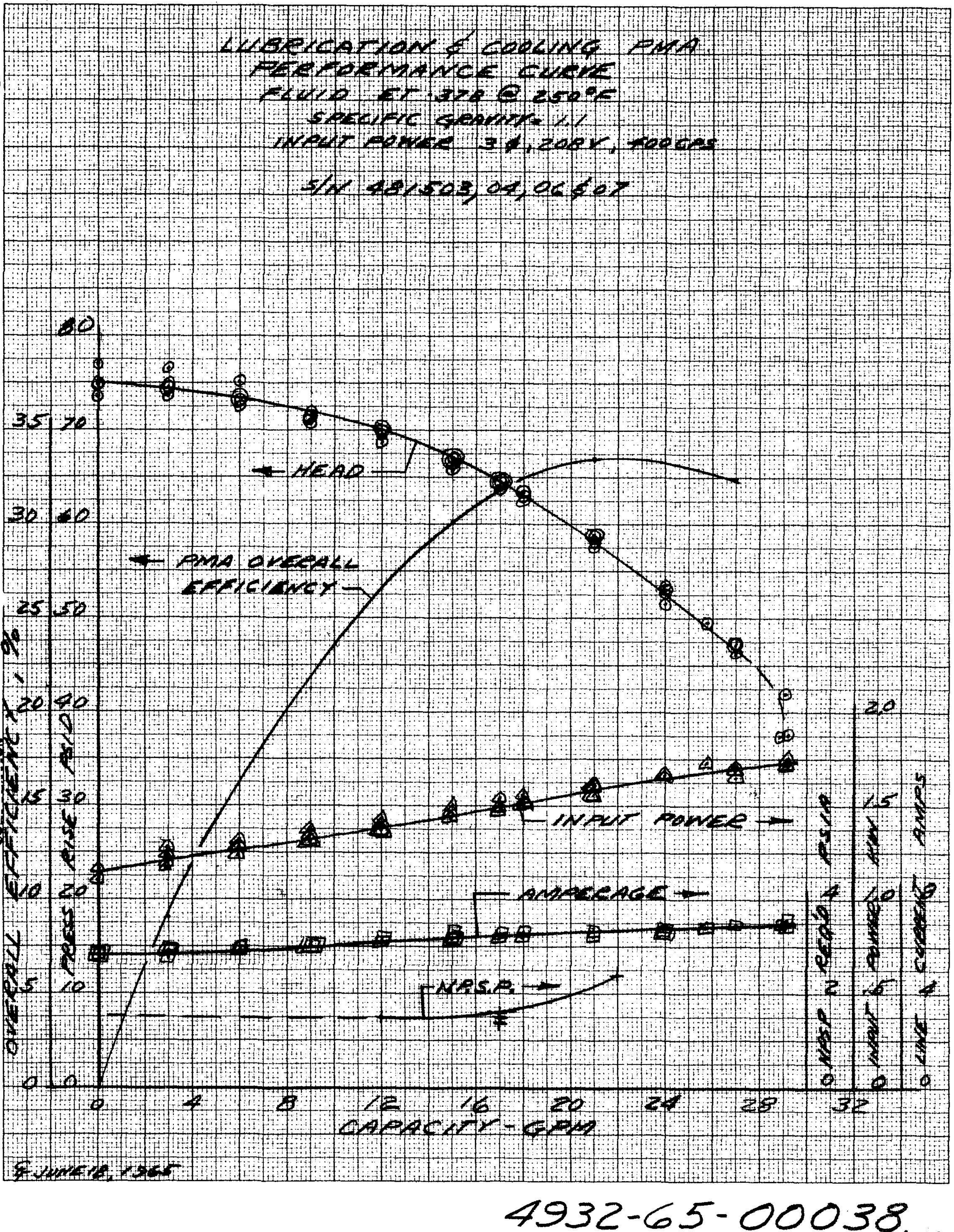


4832-65-00007

A-10

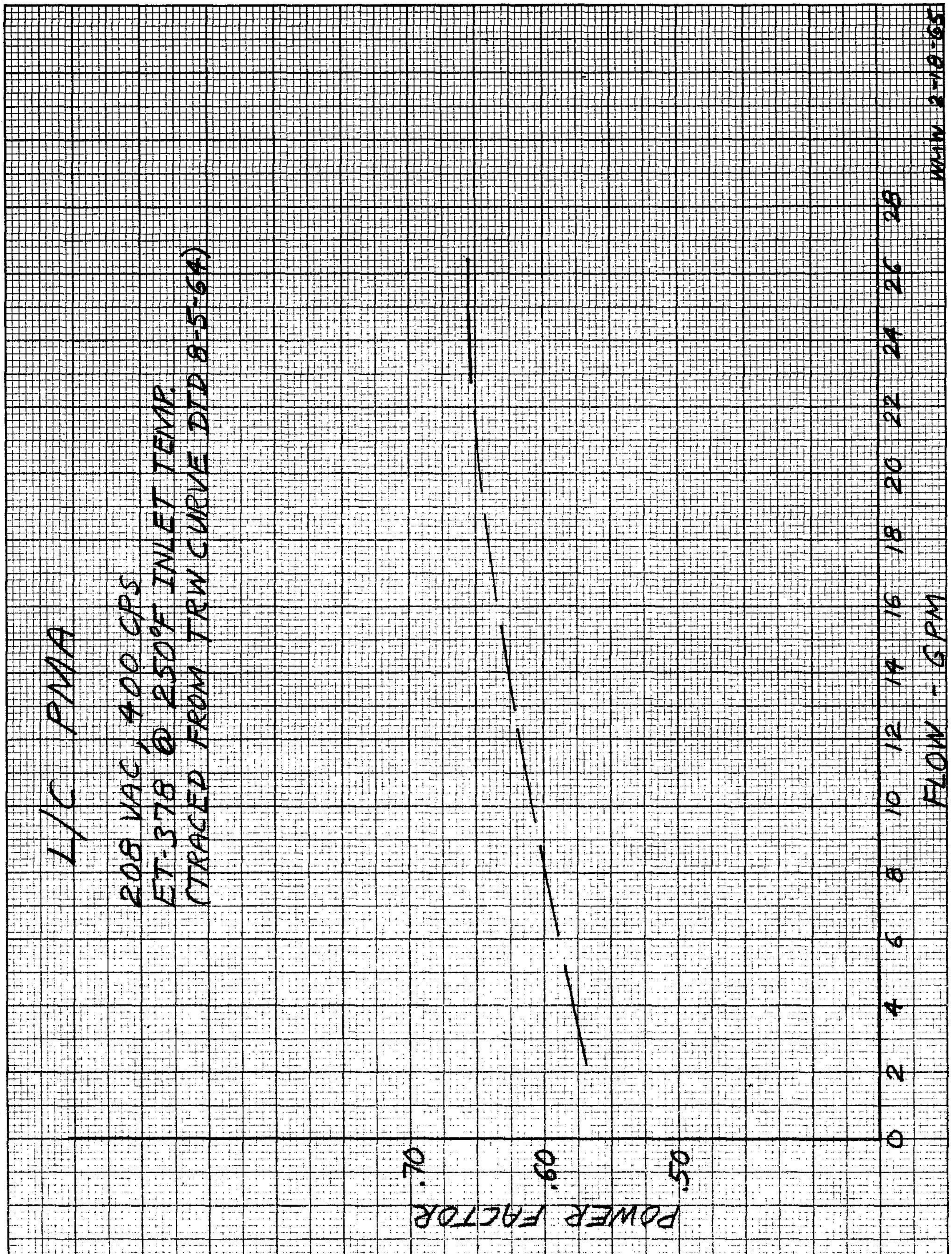


4832-64-00180



4932-65-00038

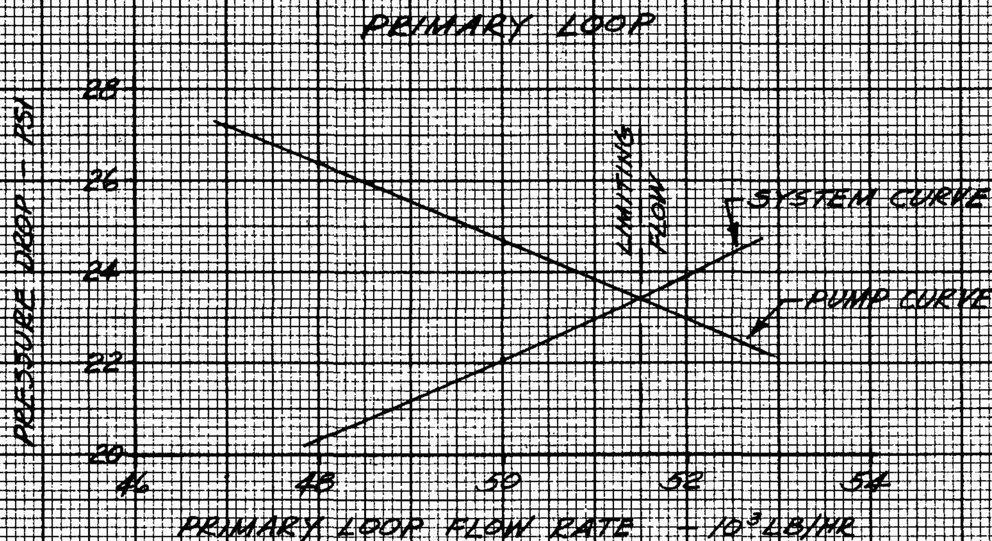
A-12

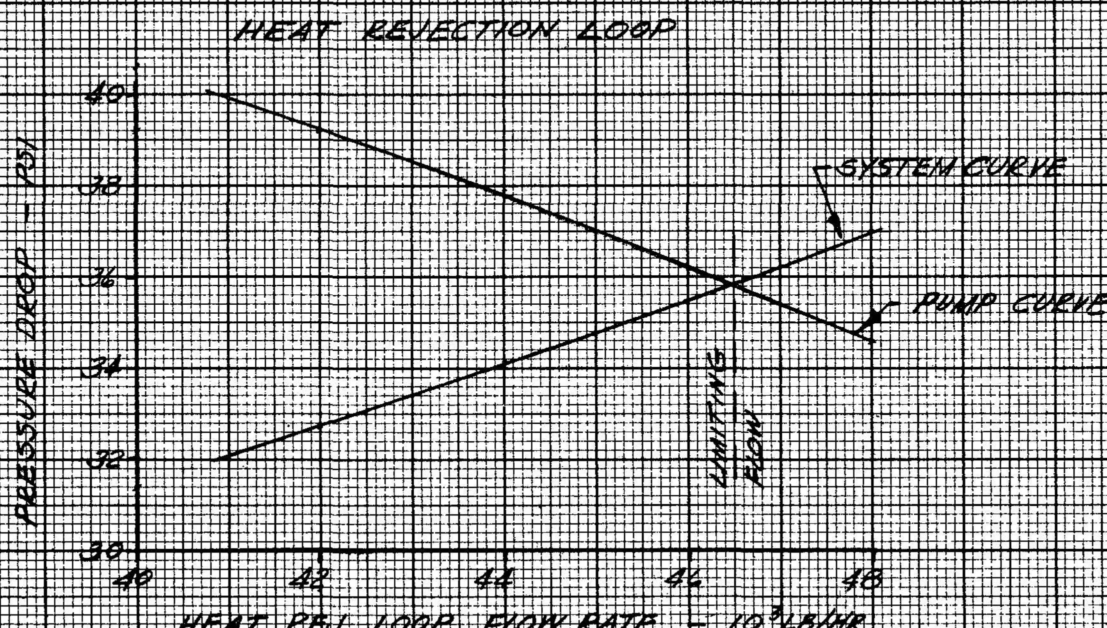


18 Feb. 1965
WMW

4832-65-00006

LIMITING FLOW RATES IN PRIMARY & HEAT REJECTION LOOPS
(FOR SNAP-8 EGS USING UNMODIFIED -1 COMPONENTS)





RGG 9-1-65

APPENDIX B

SAMPLE CALCULATIONS FOR SYSTEM ANALYSIS

A set of system calculations is presented to illustrate the procedure used in determining the values shown on the SNAP-8 EGS Performance Diagrams which are based on the performance of unmodified -1 components.

UPPER TEMPERATURE LIMIT

1. ASSUME: $w_{Hg_{TOT}} = 12000$ LB/HR $\quad w_{Hg_V} = 11760$ LB/HR $\quad w_N = 46000$ LB/HR
$T_{N_{IN}} = 1330°F \quad T_{Hg_{OUT}} = 1300°F \quad P_{TEX} = 14.5$ PSIA

2. VAPOR SYS CALCS
$P_{COND_{IN}} = 14.5 - .5 = 14.0$ PSIA $\quad T_{Hg_{COND_{IN}}} = 670°F \quad T_{N_{COND_{OUT}}} = 660°F$
$P_{PUMP_{IN}} = 14 - 1 = 13.0$ PSIA
$T_{TURB_{IN}} = 1290°F = 1750°R$
$P_{TURB_{IN}} = \frac{11760\sqrt{1750}}{2050} = 240$ PSIA
$P_{B_{OUT}} = 240 + 10\left(\frac{12000}{11750}\right)^2 = 250.4$ PSIA

3. BOILER CALCS: $\quad (\Delta T_{PP} = 73°F$ FROM BOILER PERF. CURVES)
$\Delta P_{B_{TOT}} = \left(\frac{12000}{11500}\right)^2 \left[27.3 + \overset{73.4}{.7 \times 73}\right] = 85.2$ PSI
$\Delta P_L = 17\left(\frac{12000}{11500}\right)^2 = 18.5$ PSI
$\therefore P_{B_{IN}} = 335.6$ PSIA $\quad P_{INT} = P_{SAT} = 317.1$ PSIA
$\therefore T_{SAT} = 1101°F$

$\Delta h_{fg} = 123.0 \quad \Delta h_{SH} = .0252(1300 - 1101) = 5.0$
$\Delta T_{N_{B+SH}} = \frac{128.0 \times 11760}{.21 \times 46000} = 156° \quad , \quad T_{N_{INT}} = 1330 - 156 = 1174°$
$\therefore \Delta T_{PP} = 1174 - 1101 = 73°F$ (CHECKS WITH ASSUMPTION)

ASSUME $T_{Hg_{B_{IN}}} = 500°F$
$\Delta h_{PH} = .0324(1101 - 500) = 19.5$
$\Delta T_{N_{PH}} = \frac{19.5 \times 12000}{.21 \times 46000} = 24.2°F$

$\Delta T_{N_{TOT}} = 180°F \quad , \quad T_{N_{B_O}} = 1150°F$

$Q_{B_{TOT}} = \overset{150.4 \times 10^4}{128 \times 11760} + \overset{23.4 \times 10^4}{19.5 \times 12000} = 173.8 \times 10^4$ BTU/HR $= 509$ KW

4. TURBINE - CONDENSER CALCS

$P_{T_{IN}} = 240$ $T_{T_{IN}} = 1290$ $h_{IN} = 162.8$

$P_{T_{EX}} = 14.5$ PSIA $h_{OUT} = \underline{128.3}$

$\Delta h_{ISEN} = 34.5$

$h_{EX} = h_{IN} - \eta_T(\Delta h_{ISEN}) = 162.8 - .555 \times \overset{19.15}{34.5} = 143.65$

$X_{EX} = .969$

$\Delta h_{COND} = .969 \times 126.7 = 122.8$

ASSUME $T_{N_{COND_{IN}}} = 489°$ $\Delta T_{N-HG} = 2°$ $\therefore \Delta h_{SC} = .0324(670° - 491°) = 5.8$

5. HRL CALCS

$Q_{RAD} = \overset{144.3 \times 10^4}{122.8 \times 1176} + \overset{6.96 \times 10^4}{5.8 \times 12000} = 151.26 \times 10^4$ BTU/HR $= 444$ KW

$n = \frac{444}{419.5} \times 130 = 137$ TUBES

$w_{HRL} = \frac{137}{130} \times 39300 = 41500$ LB/HR

$T_{RAD_{OUT}} = 488°F$ WITH $T_{RAD_{IN}} = 660°F$ ($\Delta T_{RAD} = 172°F$)

$\Delta T_{RAD} = \frac{151.26 \times 10^4}{.212 \times 41500} = 172°F$ (CHECKS WITH ABOVE)

$\Delta P_{HRL} = 12.3\left(\frac{41500}{39300}\right)^2 + 18.8 = 13.6 + 18.8 = 32.4$ PSI

$Q_{PUMP} = 101.8$ GPM $\Delta P_{PUMP} = 112.7 \times .3525 = 39.8$ PSI

PUMP CAN MEET SYSTEM REQMT.

6. POWER CALCS!

$P_{TURB_{OUT}} = \frac{.555 \times 1176 \times 34.5}{343} = 66.0$ KW

$P_{SHAFT} = P_{TURB_{OUT}} - P_{\substack{BRGS \\ SH. SEAL}} = 66.0 - 3.3 = 62.7$ KW

SYSTEM POWER REQMTS

	KW	p.f.	KVA	θ	sin θ	KVA sin θ
MPMA	2.86	.725	3.94	43.5	.6884	2.71
NPMA	4.3	.525	8.19	58.7	.8545	7.0
HRL-PMA	4.4	.53	8.3	57.5	.8434	7.0
L/C-PMA	1.43	.63	2.27	51	.777	1.77
PLR+SC	5.5	.35	15.7	69.5	.9367	14.7
LOAD	35.0	.75	46.7	41.4	.6613	30.9
	53.49		86.1			64.08

$$\theta_{ALT} = \tan^{-1}\left(\frac{64.08}{53.49}\right)^{1.198} = 50.2° \quad , \quad p.f. = \cos 50.2° = .640$$

FROM ALT. PERF CURVES $\eta_{ALT} = .86$

$P_{ALT_{OUT}} = .86 \times 62.7 = 54.0$ KW (AVAIL)

$P_{ALT} = 53.5$ KW (REQ'D)

0.5 KW — CONSIDER AS MARGIN

$KVA_{ALT} = 86.1 + .6 = 86.7 < 87.5$ (BELOW LIMIT)

7. MERCURY LOOP, LIQUID RESISTANCE

$P_{B_{IN}} = 335$ PSIA

$w_{Hg_{TOT}} = 12000$ LB/HR $\quad Q_P = 1.855$ GPM , $\Delta P_{PUMP} = 875 \times .561 = 491$ PSI

$P_{PUMP_{OUT}} = 491 + 13 = 504$ PSIA

$\therefore \Delta P_{LR} = 504 - 335 = 169$ PSI

LOWER TEMPERATURE OPERATION

1. ASSUME: $w_{Hg_{TOT}} = 12500$ LB/HR $\quad w_{Hg_V} = 12250$ LB/HR $\quad w_N = 46000$ LB/HR

$T_{N_{IN}} = 1280$ °F $\quad T_{Hg_{OUT}} = 1250$ °F $\quad P_{EX} = 16.0$ PSIA

$w_{HRL} = 41500$ LB/HR

2. VAPOR – SYS CALCS:

$P_{COND_{IN}} = 16.0 - .5 = 15.5$ PSIA , $\quad T_{Hg_{COND_{IN}}} = 680$

$P_{PUMP_{IN}} = 15.5 - 1 = 14.5$ PSIA $\quad T_{N_{COND_{OUT}}} = 680 - 10 = 670°$

$T_{TURB_{IN}} = 1250 - 10 = 1240°F = 1700°R$

$$P_{TURB_{IN}} = \frac{12250\sqrt{1700}}{2050} = 246.5 \text{ PSIA}$$

$$P_{B_{OUT}} = 246.5 + 10\left(\frac{12500}{11750}\right)^2 = 258 \text{ PSIA}$$

QUADRILLE WORK SHEET

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE 8-21-65

SUBJECT ______ BY ______ WORK ORDER ______

3. BOILER CALCS: ($\Delta T_{PP} = 31°F$ — FROM BOILER PERF CURVES)

$$\Delta P_{B_{TOT}} = \left(\frac{12500}{11500}\right)^2 \left[27.3 + .7 \times 31\right] = 57.9 \text{ PSI}$$

$$\Delta P_L = 17\left(\frac{12500}{11500}\right)^2 = 20.1 \text{ PSI}$$

$\therefore P_{B_{IN}} = 315.9$, $P_{B_{INT}} = P_{SAT} = 295.8$ PSIA

$\therefore T_{SAT} = 1088°F$

$\Delta h_{fg} = 123.1$ $\quad$ $\Delta h_{SH} = .0252(1250 \overset{162}{-} 1088) = 4.08$

$$\Delta T_{N_{BTSH}} = \frac{127.18 \times 12250}{.21 \times 46000} = 162°F$$

$T_{N_{INT}} = 1280 - 162 = 1118°$ $\quad$ $\therefore \Delta T_{PP} = 1118 - 1088 = 30°$ (CHECKS CLOSE ENOUGH WITH ASSUMPTION)

4. PUMP-SYSTEM PRESS MATCH

$$\Delta P_{LR} = 169\left(\frac{12500}{12000}\right)^2 = 184 \text{ PSI}$$

$P_{PUMP_{OUT}})_{REQD} = P_{B_{IN}} + \Delta P_{LR} = 315.9 + 184 = 500$ PSIA

$Q_{PUMP} = 1.93$ GPM , $\Delta P_{PUMP} = 87 \times 5.61 = 488$ PSI

$P_{PUMP_{OUT}})_{AVAIL} = 488 + 14.5 = 502.5$ PSIA

DOES NOT CHECK CLOSE ENOUGH

$\therefore$ ITERATE L.D.B. OPERATION ASSUMING HIGHER w_{HG}

———— o ————

LOWER TEMPERATURE OPERATION

1. ASSUME: $w_{HG_{TOT}} = 12550$ LB/HR, $w_{HG_V} = 12300$ LB/HR $\quad w_N = 46000$ LB/HR

$w_{HGL} = 41500$ LB/HR $\quad P_{TEX} = 16.0$ PSIA

2. VAPOR SYS CALCS

$P_{COND_{IN}} = 15.5$ PSIA $\quad T_{HGCOND_{IN}} = 680°F$

$P_{PUMP_{IN}} = 14.5$ PSIA $\quad T_{NCONDOUT} = 670°F$

$T_{TURB_{IN}} = 1240°F = 1700°R$

$$P_{TURB_{IN}} = \frac{12300\sqrt{1700}}{2050} = 247.5 \text{ PSIA}$$

$$P_{B_{OUT}} = 247.5 + 10\left(\frac{12550}{11750}\right)^2 = 258.9 \text{ PSIA}$$

01-071-002

QUADRILLE WORK SHEET

AEROJET GENERAL

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AZUSA, CALIFORNIA

PAGE B-5 OF ____ PAGES

DATE 8-21-65

SUBJECT ____ BY ____ WORK ORDER ____

3. BOILER CALC'S: ($\Delta T_{PP} = 30°F$ – FROM BOILER PERF. CURVES)

$$\Delta P_{B_{TOT}} = \left(\frac{12550}{11500}\right)^2 \left[27.3 + .7 \times 30\right] = 57.5 \text{ PSI}$$

$$\Delta P_L = 17\left(\frac{12550}{11500}\right)^2 = 20.2 \text{ PSI}$$

$\therefore P_{B_{IN}} = 316.4$ PSIA , $P_{B_{INT}} = P_{B_{SAT}} = 296.2$ PSIA

$\therefore T_{SAT} = 1088°F$

$\Delta h_{fg} = 123.1$ $\quad \Delta h_{SH} = .0252(1250 - 1088) = 4.08$

$$\Delta T_{N_{B\,SH}} = \frac{127.18 \times 12300}{.21 \times 46000} = 162°F$$

$T_{N_{INT}} = 1280 - 162 = 1118°F$, $\therefore \Delta T_{PP} = 1118 - 1088 = 30°$ (CHECKS WITH ASSUMPTION)

4. PUMP-SYSTEM PRESS. MATCH

$P_{B_{IN}} = 316.4$ PSIA $\quad \Delta P_{LR} = 169\left(\frac{12550}{12700}\right)^2 = 185$ PSI

$P_{PUMP_{OUT}}\Big)_{REQD} = 316.4 + 185 = 501.4$ PSIA

$Q_{PUMP} = 1.94$ GPM $\quad \Delta P_{PUMP} = 87 \times 5.61 = 488$ PSI

$P_{PUMP_{OUT}}\Big)_{AVIAL} = 488 + 14.5 = 502.5$ PSIA (CHECKS CLOSE ENOUGH WITH REQUIRED VALUE)

5. TURBINE-CONDENSER CALCS

$P_{T_{IN}} = 247.5$ PSIA $\quad T_{T_{IN}} = 1240°F$

$P_{T_{EX}} = 16.0$ PSIA

$h_{IN} = 161.5$
$h_{EX} = 128.0$
$\Delta h_{ISEN} = 33.5$

$h_{EX} = 161.5 - .555 \times 33.5 = 142.9$

$X_{EX} = .962 \times 126.55 = 121.7$

ASSUME $T_{N_{COND_{IN}}} = 490°$ $\quad \Delta T_{N-Hg} = 2°$ $\quad \therefore T_{Hg_{COND_{OUT}}} = 492°$

$$\Delta h_{SC} = .0324(670 - 492) = 5.96$$

6. HRL CALCS:

$$Q_{RAD} = \overset{149.8\times10^4}{121.7 \times 12300} + \overset{7.49\times10^4}{5.96 \times 12550} = 157.29 \times 10^4 \text{ BTU/HR} = 461 \text{ KW}$$

FOR $n = 137$ TUBES & $\dot{w}_{HRL} = 41500$ #/HR ,

461 KW IS EQUIV TO $461 \times \frac{130}{137} = 437$ KW (ON RAD. PERF. CURVES)

TO OBTAIN 461 KW (445 KW ON RAD CURVES) $T_{R_{IN}} = 677°F$ & $T_{R_O} = 497°F$
(DOES NOT AGREE WITH ASSUMPTION)

01-071-002

QUADRILLE WORK SHEET

AEROJET GENERAL

AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE 8-21

SUBJECT ______ BY ______ WORK ORDER ______

LOWER TEMPERATURE OPERATION

1. ASSUME: $w_{H_{GTOT}} = 12600$ LB/HR , $w_{H_{GV}} = 12350$ LB/HR , $w_N = 46000$ LB/HR
$w_{HRL} = 41500$ LB/HR $\qquad P_{TEX} \simeq 16.8$ PSIA

2. VAPOR SYS. CALCS

$P_{COND_{IN}} = 16.3$ PSIA $\qquad T_{H_{COND_{IN}}} = 686°F \qquad T_{N_{COND_{OUT}}} = 686 - 10 = 676°F$

$P_{PUMP_{IN}} = 15.3$

$T_{TURB_{IN}} = 1240°F$

$$P_{TURB_{IN}} = \frac{12350\sqrt{1700}}{2050} = 248 \text{ PSIA}$$

$$P_{B_{OUT}} = 248 + 10\left(\frac{12600}{11750}\right)^2 = 259.5 \text{ PSIA}$$

3. BOILER CALCS: ($\Delta T_{PP} \approx 30°$ – FROM BOILER PERF. CURVES)

$$\Delta P_{B_{TOT}} = \left(\frac{12600}{11500}\right)^2 \left[27.3 + .7 \times 30\right] = 57.9 \text{ PSI}$$

$$\Delta P_L = 17\left(\frac{12600}{11500}\right)^2 = 20.4 \text{ PSI}$$

$\therefore P_{B_{IN}} = 317.4$ PSIA $\quad , \quad P_{B_{INT}} = P_{SAT} = 297$ PSIA

$\therefore T_{SAT} = 1088°F$

$\Delta h_{fg} = 123.1 \qquad \Delta h_{SH} = .0252\,(1250 - 1088) = 4.08$

$$\Delta T_{NB, SH} = \frac{127.18 \times 12350}{.21 \times 46000} = 162.5°F$$

$T_{N_{INT}} = 1280 - 162.5 = 1117.5°F \qquad \therefore \Delta T_{PP} = 1117.5 - 1088 = 29.5°F$
(CHECKS CLOSE ENOUGH WITH ASSUMPTION)

4. PUMP – SYSTEM PRESS. MATCH

$P_{B_{IN}} = 317.4$ PSIA $\qquad \Delta P_{LE} = 169\left(\frac{12600}{12000}\right)^2 = 187$ PSI

$P_{PUMP_{OUT}})_{REQD} = 317.4 + 187 = 504$ PSIA

$Q_{PUMP} = 1,945$ GPM $\qquad \Delta P_{PUMP} = 87 \times 5.61 = 488$ PSI

$P_{PUMP_{OUT}})_{AVAIL} = 488 + 15.3 = 503$ PSIA (CHECKS CLOSE ENOUGH WITH REQUIRED VALUE)

5. TURBINE–CONDENSER CALCS:

$P_{T_{IN}} = 248$ PSIA $\quad T_{T_{IN}} = 1240°F$

$P_{T_{EX}} = 16.8$ PSIA

$h_{IN} = 161.5$

$h_{OUT} = 128.1$

$\Delta h_{ISEN} = 33.4$

$h_{EX} = 161.5 - .555 \times 33.4 = 142.95$ (18.55)

$X_{EX} = .962$

$h_{EX} = .962 \times 126.5 = 121.7$

ASSUME $\quad T_{NCOND_{IN}} = 498°F \quad \Delta T_{N-HG} = 2° \quad \therefore T_{HG_{COND_{OUT}}} = 500°F$

$\Delta h_{SC} = .0324(676 - 500) = 5.70$

6. HRL CALCS:

$Q_{RAD} = \overset{150.2\times10^4}{121.7 \times 12350} + \overset{7.18\times10^4}{5.7 \times 12600} = 157.38 \times 10^4$ BTU/HR $= 461$ KW

FOR $n = 137$ TUBES & $w_{HRL} = 41500$ LB/HR;

461 KW IS EQUIV. TO 437 KW

TO OBTAIN 461 KW (437 KW ON RAD. CURVES) $\quad T_{R_{IN}} = 677°F \quad T_{R_{OUT}} = 497°F$

$\Delta T_{RAD} = 180°F$

$\therefore$ RADIATOR INLET & OUTLET TEMPS CHECK CLOSELY WITH ASSUMPTIONS (~1°)

7. POWER CALCS

$$P_{TURB_{OUT}} = \frac{.555 \times 12350 \times 33.4}{3413} = 67.1\text{ KW}$$

$$P_{T_{SHAFT}} = P_{T_{OUT}} - P_{\substack{BRGS \\ SP. SEAL}} = 67.1 - 3.3 = 63.8\text{ KW}$$

SYSTEM POWER REQMTS: UNCHANGED FROM CALCS FOR UPPER DEAD BAND OPERATION (P.B-3); EXCEPT MPMA INCREASES FROM 2.86 KW TO 2.87 KW WHICH IS NEGLIGIBLE

$\therefore \; P_{ALT})_{REQD} = 53.5$ KW $\quad , \quad \eta_{ALT} = .86$

$\therefore \; P_{ALT})_{AVAIL} = .86 \times 63.8 = 54.8$ KW

$\therefore$ 1.3 KW MARGIN OR EXCESS POWER IS PRODUCED

$KVA_{ALT} \simeq 86.1 + 1.6 = 87.7$ (AT CONSERVATIVE LIMIT)

8. BOILER HEAT

$$T_{N_{COND_{IN}}} = T_{RAD_{OUT}} + \Delta T_{\substack{NRL \\ PUMP}} = 497 + 1 = 498°F$$

$$T_{HG_{COND_{OUT}}} = T_{N_{COND_{IN}}} + \Delta T_{N-HG} = 498 + 2 = 500°F$$

$$T_{HG_{B_{IN}}} = T_{HG_{COND_{OUT}}} + \Delta T_{\substack{HG \\ PUMP}} = 500 + 9 = 509°F$$

$$\therefore \; Q_{PH} = .0324 \times 12600 \left(1088 \overset{579}{-} 509\right) = 23.6 \times 10^4 \; BTU/HR$$

$$Q_{B+SH} = 127.18 \times 12350 = 1.57 \times 10^6 \; BTU/HR$$

$$Q_{B_{TOT}} = 180.6 \times 10^4 \; BTU/HR = 529 \; KW$$

$$\Delta T_{B_{TOT}} = \frac{180.6 \times 10^4}{.21 \times 46000} = 187°F \qquad \therefore \; T_{N_{B_{OUT}}} = 1280 - 187 = 1093°F$$

01-071-002

QUADRILLE WORK SHEET

AEROJET GENERAL
AEROJET-GENERAL CORPORATION
AZUSA, CALIFORNIA

DATE 8-21-65

SUBJECT ______ BY ______ WORK ORDER ______

ADDITIONAL MISC. CALCS:

1. CHECK ON $T_{HG_{BIN}}$ FOR UPPER DEADBAND OPERATION

$T_{N_{COND\,IN}} = 488 + 1 = 489°$

$T_{HG_{COND\,OUT}} = 489 + 2 = 491°$

$T_{HG_{BIN}} = 491 + 9 = 500°F$ CHECKS WITH ASSUMPTION ON P. B-1